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У статтях збірника містяться матеріали наукових досліджень і проектно-конструкторських робіт, спрямованих на вдосконалення технології та техніки лісового господарства, лісової, паперової, деревообробної промисловості та економіки.

Збірник розрахований на наукових, інженерно-технічних працівників, а також студентів, які виявляють інтерес до наукової діяльності.

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FURNITURE INDUSTRY IN EASTERN EUROPE: CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE DEVELOPMENT

The paper presents results of research performed for furniture industry. The present researching is based on the comparison of the furniture industries for three ENP countries (Ukraine, Moldova and Georgia) in the one hand and furniture industries of Poland and Austria from the other. In the process of the researching authors of this paper: a) carried out analysis of the furniture industry development for the period from 2008 to 2012 in researching countries on the base of absolute indexes; b) presented comparative analysis for 2012 on the base of the main parameters for furniture industry of the mentioned above countries on the base of relative indexes; c) identified regression model which determines dependence of such very important value as turnover per capita in furniture industry from the following indexes - number of enterprises in furniture manufacturing per 1 mil inhabitants, average number of employees per enterprise in the national scale, GDP per capita, volume of the produced industrial round wood per capita, volume of the produced fiberboard per 1000 persons, volume of the produced particleboard per 1000 persons. As a result on the base of the carried out researching it has been identified main challenges and opportunities of the sustainable production for furniture industry in Eastern Europe.

Keywords: furniture industry, comparative analysis, regression model, ENP countries.

Introduction. Future sustainable development of the furniture industry in Eastern Neighborhood Partnership countries, especially in such countries as Ukraine, Georgia and Moldova is extremely important. There are at least a few reasons why it should consider furniture manufacturing in these countries as such that deserves especial attention and additional researching:

- furniture industry is one of the most important consumer of such unique resource as forest [Osses et al. 2013]and therefore development of this industry can offer a simple way to reduce the CO_2 emissions that is the main cause of Climate Change, through the carbon storage effect of wood products and substitution effect of carbon-intensive materials;
- Ukraine, Georgia and Moldova have signed trade agreement with EU and have announced their commitments to EU direction and nowadays economic development for these countries gains especially considerable value;
- there are some objective prerequisites in ENP countries for furniture industry development: they hold sufficient forest resources [Kiyko 2009, Kiyko, Kiyko I. 2012, Gayda 2011-2015]; current level of the furniture industry development is under average EU level and therefore needs considerable improving; there is constant internal demand for furniture pieces in these countries; comparing with some other sub industries furniture manufacturing needs investments but in no such scale as others (for instance automobile industry or infrastructure development); the wood-based industries, emerging anew in post-socialist economies, play a key role in regional development, as they could develop an even stronger impact on regional production, employment and value adding on the basis of regional natural resources simultaneously involving rich regional resource of highly qualified staff and using SMs potential;
- ENP countries hold considerable, yet less developed forest resources with a comparatively average lower land use pressure than in Western Europe [Kiyko O. 2009, Kiyko O., Kiyko I. 2012] and the main point in this regard is the following - a constantly growing demand for wood raw materials in European markets leads to higher raw material import and growing pressure on forests holding substantial, unexploited wood resources in neighbouring Eastern Europe. The main challenge here is to support the development of sustainable management regimes of the abundant resource.

As a rule, for furniture industry development and perspectives evaluation it is using benchmarking approach [Hitka, Sirotiakovà 2012, Smardzewski 2009] which allows to determine current place in some hierarchy (regional, continental or whole world), industrial network approach [Ratajczak-Mrozek, Herbeć 2014] or mathematical model creation which allows to forecast some future directions for industry or economic sector improving [Kiyko O., Kiyko I. 2012, Merková et al.2012]. Each of these approaches has some advantages and we can assume that combining them will give some positive synergetic effect for any researching.

Research methodology. The presented researching comprises three successive stages.

1. Evaluation of the furniture industry dynamic for five-year period beginning from 2008 and finishing to 2012. Researching of the dynamics for the furniture industry development was carried out only for four countries: Ukraine, Moldova, Georgia and Poland. As the main parameters for any furniture industry identifying we used the following absolute indexes: overall turnover; number of enterprises; number of employees. Within the frameworks of the absolute indexes counting it was determine that level of the 2008 (the first year of the researching period) is equal to 100 %. The main aim of this stage was an evaluation of the five-year period in regard to furniture manufacturing development before and after world financial crises that was occurred in 2009-2010.

2. Comparative analysis of the furniture industry for five countries (Ukraine, Moldova, Georgia, Poland and Austria). Within the frameworks of this analysis it was used only the following relative indexes for 2012:

- turnover per enterprise in furniture manufacturing;
- turnover per employee in furniture manufacturing;
- number of furniture enterprises per 1 million inhabitants;
- average number of employees per furniture enterprise.

The main aim of this comparison was to identify some disadvantages of the furniture industry in ENP countries.

3. Creation of the mathematical regression model for forecast making in regard to furniture industry development. This stage included sample coefficient of the correlation determining and regression equation receiving.

Sample coefficient of the correlation r was counted as shown in (1):

$$r = \frac{\sum_{i=1}^{N} (x_i - \bar{x}) \cdot (y_i - \bar{y})}{(N - 1) \cdot S_x \cdot S_y}. \tag{1}$$

where: **x** and **y** are two random values between which sample coefficient of the correlationwas counted; $\bar{x}$ and - $\bar{y}$ - two average samples; $\mathbf{S_x}$ and $\mathbf{S_y}$- two standard deviations.

As a regression equation it was used the first and the second degree polynomials. Linear dependence it was presented as shown in (2):

$$\boldsymbol{y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i,u=1}^{k} b_{iu} x_i x_u}, \tag{2}$$

where: $\boldsymbol{b_0}$ - free member; $\boldsymbol{b_i}$ - factor's coefficients; $\boldsymbol{b_{iu}}$ - coefficientsfor factor'sinteractions, moreover - i≠и.

Quadratic dependence it was presented as shown in (3)

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i,u=1}^{k} b_{iu} x_i x_u + \sum_{i=1}^{k} b_{ii} x^2 \tag{3}$$

where: b_{ii} - coefficientsfor factorsin the second degree.

After verification of these two models linear dependence was chosen as an adequate and more precise one. The accuracy ofthe modelwas determinedby means of such parameter asthe sum of squared deviations of differences. In the case of linear model this sum was $1{,}4\cdot10^{-19}$ and in the case of quadratic model this value was equal to $4\cdot10^{-3}$. The presented researching is based on the comparison of the furniture manufacturing in three ENP countries (Ukraine, Moldova and Georgia) in the one hand and Polish and Austrian furniture industries from the other. This “country choice” was motivated by the following reasons:

- Ukraine, Moldova and Georgia are ones of the most important in economic terms representatives of Eastern Partnership;
- Ukraine, Moldova and Georgia declare their commitments to the European way of development and it is important to evaluate their “forest possibilities” at the beginning of this way;
- Austria has one of the most powerful forest sector in the Europe;
- Poland is a country which has passed the way from country of socialist camp to the one of the EU leader;
- there are a lot of similarities between furniture sectors of Ukraine and Poland;
- there are some similarities between forest sectors of Moldova and Georgia.

Results and discussion. Analysis of the furniture industry development carried out on the base of absolute indexes. The main indexes of the furniture industry development for researching countries are presented in table 1.

Table1. Furniture industry development in Ukraine, Georgia, Moldova and Poland for period from 2008 to 2012

Parameters/ Years	2008	2009	2010	2011	2012
Ukraine					
Turnover, bil. UAH	5,4	3,9	4,9	6,2	7,2
Number of enterprises, units	1676	1700	5539	1512	1548
Number of employees, ths. persons	51,3	39,8	38,7	37,1	38,5
Moldova					
Turnover, bil. MDL	0,64	0,55	0,61	0,72	0,69
Number of enterprises, units	225	275	327	362	370
Number of employees, ths. persons	3,6	3,3	3,5	2,5	2,7
Georgia					
Turnover, mil. EUR	9,82	7,56	23,52	38,82	42,76
Number of enterprises, units	193	434	418	401	387
Number of employees, persons	885	1166	1513	2325	2650
Poland					
Turnover, mil. PLN	26419	27724	25728	30182	28788
Number of enterprises, units	24980	24806	26488	26488	27047
Number of employees, ths. persons	153,1	151,0	144,9	144,3	138,6

The main goal of the comparison regarding furniture industry development for four countries was evaluation of the post crises situation in these countries. In order to analyze overall situation in furniture manufacturing it has been used such three parameters as turnover (fig. 1), number of enterprises (fig. 2) and number of employees (fig. 3).

Considering 2008 level as 100 % it is interesting that in 2012 the largest increasing of the turnover for furniture industry we had in Georgia (335 %) butfor other countries –much less (33 % in Ukraine, 8 % in Moldova and 9 % in Poland (fig. 1)). As it is presented in fig. 2, considerable changes in regard to number of the furniture enterprises for five years period was identified in Moldova (+ 64%) and in Georgia (+100%) while in Ukraine and in Poland we cannot call these changes as considerable ones (+8% and -8% respectively). Analyzing such very important for any industry index as number of employees it can point out that excluding Georgia (+199 %) it can observe decreasing of this number in all other countries (- 25% in Ukraine; -25 % in Moldova; -10 % in Moldova).

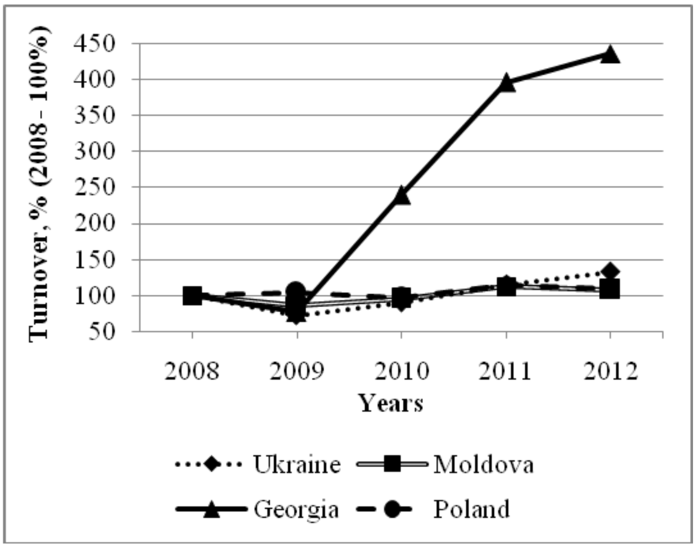

Fig. 1. Changes of the turnover for furniture industry

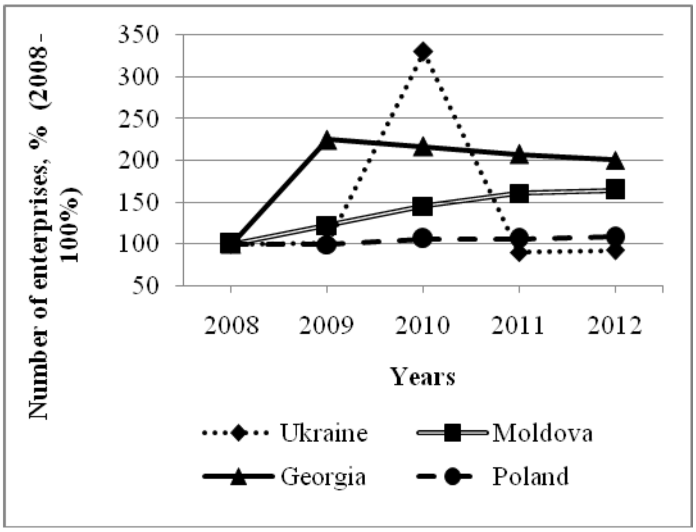

Fig 2. Changes of the number of enterprises for furniture industry

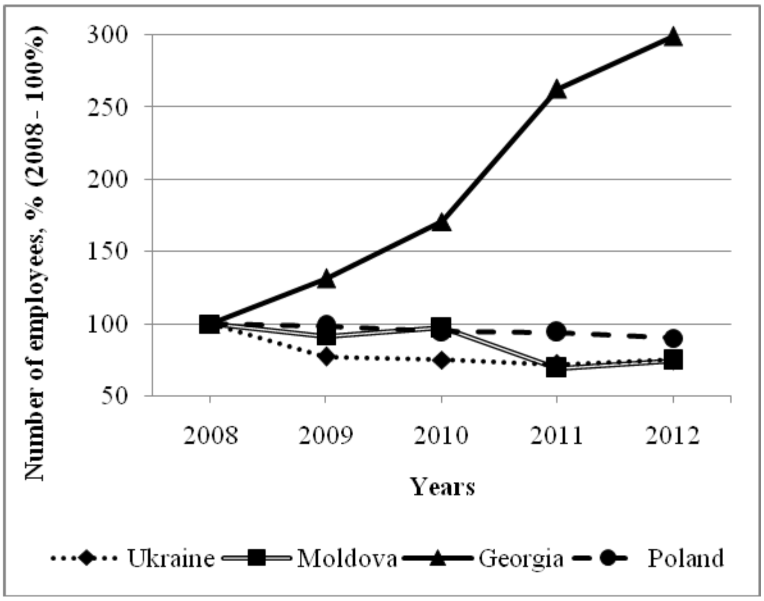

Fig. 3. Changes of the number of employees for furniture industry

Previous comparison carried out on the base of analysis of the dynamics of furniture manufacturing for ENP countries (Ukraine, Moldova and Georgia) and EU member (Poland) shows that:

- furniture industry of Georgia is the most dynamic manufacturing since for the five years period from 2008 to 2012 increasing here was the following: 335 % in turnover terms; 100 % in number of enterprises terms; 199 % in number of employee terms. It will be reasonable to explain such considerable and fast development by vital economic reforms in this country;
- furniture industry of Ukraine regarding it's dynamics for five years period can be characterize by the following features: 33% of the turnover increasing presents very weak growing, that can be consider as an increasing within the frameworks of current inflation level; 18 % decreasing of the number of enterprises and 25 % reducing of the number of employees indicate that furniture industry of Ukraine is very weak branch of national economy and maybe the most suitable characteristic in this regard is "unsustainable industry";
- furniture industry of Moldova has a lot of similarities with furniture industry of Ukraine mentioned in previous point but in reference to Moldova it is necessary to take into consideration poor forest recourses of Moldova that exercises significant influence over the development of the furniture industry (0,05 billion m^3 of overall timber stock in Moldova against 2 billion m^3 of overall timber stock in Ukraine);
- relatively constant parameters characterizing the Polish furniture industry, show that this industry, in contradistinction to ENP countries, it can consider as more sustainable since even during the financial crisis of 2008 it had no some sudden considerable reducing and negative changes.

In order to formulate final conclusion in regard to state of the furniture industry we need to carry out some additional researching: to analyze for instance some other indexes and factors and then to determine some mathematical relations.

Analysis of the furniture industry development carried out on the base of relative indexes. As we can see in fig. 4, furniture enterprises in ENP countries and in some EU countries are comparable since, for instance in Ukraine, turnover for average company makes up 0,45 million EUR while in Poland this index is equal to0,26 million EURper enterprise. At the first view it means that Ukrainian enterprise is more powerful then Polish one but considering such index as turnover per one employee it turns out that in average in ENP countries every employee produces much less furniture pieces in money terms than in Poland and in Austria. This very interesting situation obviously has some reason. In our opinion nowadays in Ukraine there are not so manyfurniture enterprisesthan in Poland (fig. 5). If to count number of the furniture enterprises per 1 million of inhabitants it can observe that in Ukraine such number is 20 times less than in Poland. Additionally to previous information regarding turnover it is very useful to determine number of employees for average furniture enterprise in Ukraine, Moldova, Georgia, Poland and Austria. As it shown in fig. 6, average Ukrainian furniture enterprise employs 25 persons while in Moldova and Georgia this number makes up 7, in Austria – 9 and in Poland – 5.

There are two main ways of the furniture industry development – so-called Germanand Italianways. According to the first of them it is necessary for succeeding in furniture industry to develop this industry having not much but quite powerful furniture enterprises. The main advantage of such way is existence of medium-scale and large-scale enterprises with possibility of expenditure reducing for providing of the competitive price for furniture pieces. According to so-called Italian way of development in furniture industry is provided by a lot of small and medium scale enterprises (sometimes even it means micro scale enterprises) taking into consideration such positive factors as strong competition and a wide variety of different furniture enterprises. According to our analysis such EU countries as Poland and Austria and such ENP countries as Georgia and Moldova are moving considering their furniture industries in Italian direction while Ukraine obviously has not defined its development path since there is not such number like in Italy and such capacity like in Germany. In our opinion this is very threatening economic situation.

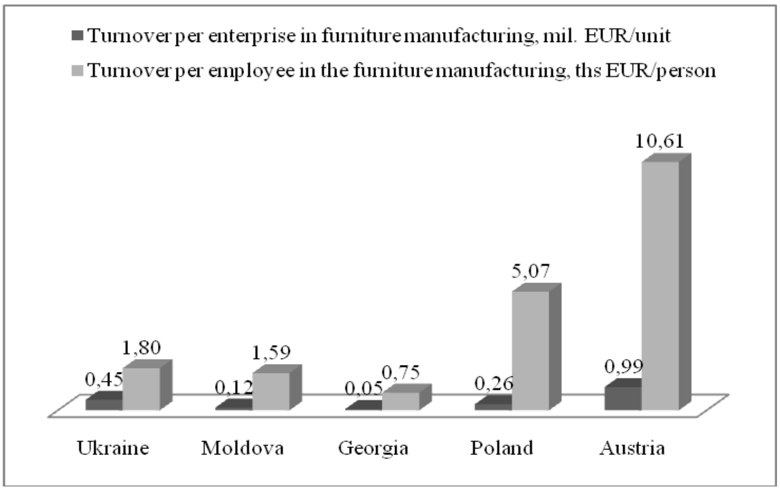

Fig. 4. Turnover for furniture industry (2012)

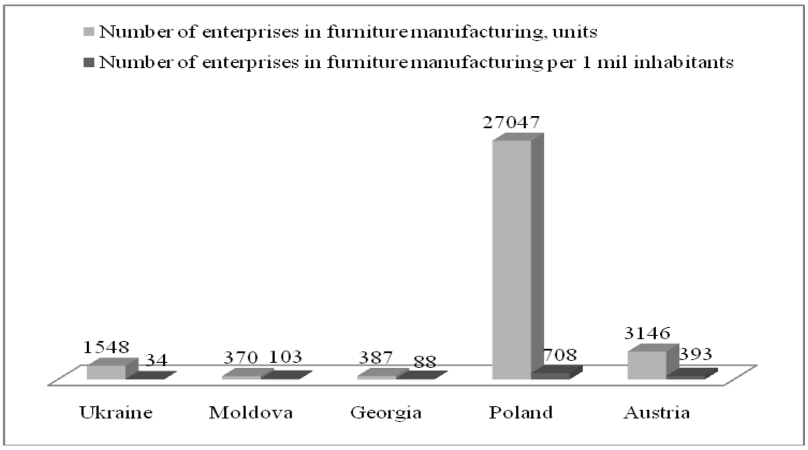

Fig. 5. Number of enterprises in furniture industry (2012)

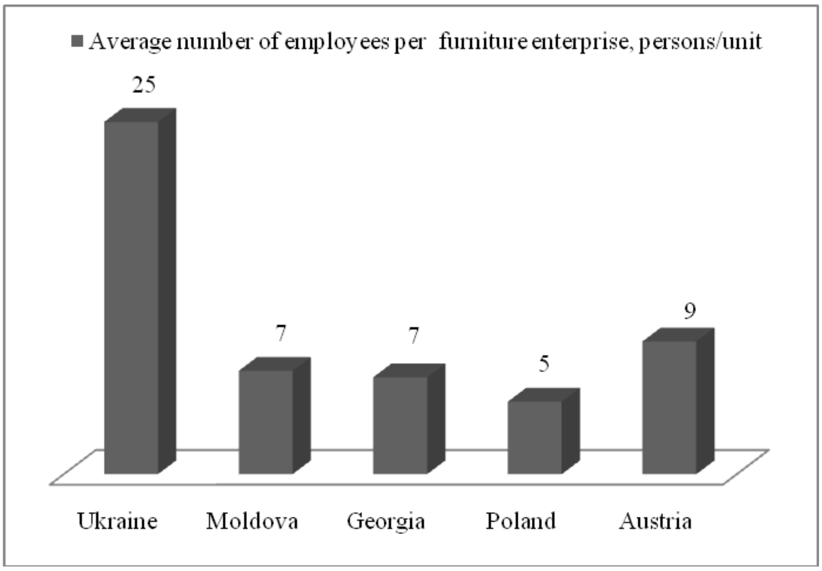

Fig. 6. Number of employees of the furniture enterprise (2012)

Regression model. As input values for the regression model creation we used indexes according to our reckoning mainly determine future development of the furniture manufacturing (tables 2, 3).

Table 2.The main indexes (2012) that impact on the furniture industry development

Country / indexes	Number of enterprises in furniture manufact. per 1 mil inhabitants	Average number of empl. per furniture enterprise pers/unit	GDP per capita (US$)	Industrial roundwood per capita, m^3/person	Fiberbord per 1000 person, m^3/1000 persons	Particle board per 1000 person, m^3/1000 persons	Annual turnover of the furniture manufact. per person, EUR/pers.
	X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**	**Y**
	N_{en}	**N_{emp}**	**G_c**	**I_r**	**F_b**	**P_b**	**T_f**
Ukraine	34	25	3873	0,17	6,61	35,18	15
Moldova	103	7	2046	0,01	0,00	0,01	12
Georgia	88	7	3528	0,02	0,00	0,23	5
Poland	708	5	12876	0,86	83,01	127,49	184
Austria	393	9	48342	1,60	93,75	281,25	391

Table 3. The Value of the coefficient of the sample correlation

Indexes	Number of enterprises in furniture manufact. per 1 mil inhabitants	Average number of empl. per furniture enterprise pers/unit	GDP per capita (US$)	Industrial roundwood per capita, m^3/person	Fiberbord per 1000 person, m^3/1000 persons	Particle board per 1000 person, m^3/1000 persons
	X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**
	N_{en}	**N_{emp}**	**G_c**	**I_r**	**F_b**	**P_b**
Value of the coefficient of the sample correlation between input value and annual turnover of the furniture manufacturing	**0,65**	**-0,26**	**0,97**	**1,00**	**0,93**	**0,99**

As a result of the data treatment, have been receivedequation of the regression (1) for output value (annual turnover of the furniture manufacturing per person)determining depending on the six independent input values (table 2):

$$\begin{aligned} T_f = {} & 2{,}4\cdot 10^{-5}+0{,}003\cdot N_{en}+0{,}0002\cdot N_{emp}-0{,}0022\cdot G_c+236{,}17\cdot I_r+7{,}8\cdot 10^{-7}\cdot F_b + \\ & +3{,}44\cdot 10^{-6}\cdot P_b+0{,}025\cdot N_{en}\cdot N_{emp}+1{,}04\cdot 10^{-5}\cdot N_{en}\cdot G_c-2{,}06\cdot 10^{-6}\cdot N_{en}\cdot I_r+ \\ & +6{,}27\cdot 10^{-5}\cdot N_{en}\cdot F_b+4{,}71\cdot 10^{-5}\cdot N_{en}\cdot P_b-0{,}0004\cdot N_{emp}\cdot G_c+9{,}38\cdot 10^{-7}\cdot N_{emp}\cdot I_r+ \\ & +5{,}76\cdot 10^{-5}\cdot N_{emp}\cdot F_b+0{,}0002\cdot N_{emp}\cdot P_b-0{,}0002\cdot G_c\cdot I_r-0{,}0003\cdot G_c\cdot F_b+ \\ & +0{,}0001\cdot G_c\cdot P_b+2{,}27\cdot 10^{-7}\cdot I_r\cdot F_b+1{,}08\cdot 10^{-5}\cdot I_r\cdot P_b+1{,}34\cdot 10^{-5}\cdot F_b\cdot P_b \qquad (4) \end{aligned}$$

Using this equation it is very easy to forecast or to count possible turnover of the furniture manufacturing per person in curtain country changing some of the input values. Changing values of these indexes for our regression model we should take into account real economic conditions, real economic prerequisites. Since today’s output index is too law, for instance, it will be very interesting to forecast furniture turnover in Ukraine (table 4). As it presented in table 4, there are three input indexes increasing of which leads to increasing of the output value.

These are industrial round wood per capita (increasing of this index on 10 % leads to increasing of the annual furniture turnover per capita on 31 % - the biggest change), number of enterprises in furniture industry and particle board manufacturing. Nature of these relations is an obvious and there is no doubt about it since actually furniture turnover depends first of all on quantity of wood resources, furniture capacity (number of the furniture enterprises) and quantity of the main construction material – particle board. At the same time, according our regression model, increasing of the number of employees at the average furniture enterprise in Ukraine we can consider as ineffective in economic terms and therefore such that leads to possible reducing of furniture turnover.

Table 4. Change (the forecasted, according regression model, value) of the furniture turnover per capita for Ukraine after increasing of the input parameter on 10 %

Name of index	Existent value of the input index (2012)	Increased on 10 % value of the input value	Existent value of the output parametr - turnover per capita (2012)	Forecasted value of the output parametr - turnover per capita	Icreasing of the output parametr, %
Number of enterprises in furniture manufacturing per 1 mil inhabitants	33,6	37,4	15,0	17,6	**17**
Average number of employees per enterprise in the national scale, persons/unit	24,9	27,4	15,0	12,5	**-17**
Industrial round-wood per capita, m^3/person	0,17	0,19	15,0	19,6	**31**
Particle board per 1000 person, m^3/1000·persons	35,2	38,7	15,0	16,5	**10**

In reference to influence of the GDP per capita in Ukraine there is some contradiction since on the one hand – the richer person the more possibility for internal furniture producing but on the other hand GDP increasing in such poor country as Ukraine not always leads to improving of the furniture manufacturing because existents of a lot of other demands beside furniture buying in this case. Taking into account this contradiction, determining of the GDP impact on the annual furniture turnover needs supplementary, circumstantial researching. And finally, in regard to influence of the MDF producing – according our model, furniture turnover dose not considerably depends on this input index maybe because fiber board, especially in Ukraine, we cannot consider as a main furniture construction material like particle board for instance.

We can accept that in Ukraine will be possible, will be real to increase such three indexes as volume of the harvested industrial round wood per capita, volume of the produced particle board per 1000 person and number of enterprises in furniture manufacturing per 1 million inhabitants. Concerning industrial wood – we can increase this value on at least to 40 % since now in Ukraine harvests approximately 17 million m^3 of the wood resources per year using only 50 % from annual increment and therefore 40 % increasing in this case will mean only 70 % usage of annual increment that agrees with international rules. There are a few quite powerful enterprises in Ukraine that all together produce annually 1,6 million m^3 of particleboards and what is more there is some possibility for increasing of existing volume in regard to particleboards manufacturing at least on 30 %.

Taking into account such two factors as new law in Ukraine according which it will be gradually implement prohibition of the round timber export (it can forecast some reactivation in furniture sector) and existing so-called “shadow” sector in furniture manufacturing which must be eliminate we can assume there is real future prerequisite for number of the furniture enterprises increasing. According our model (1) possible such future changing grounded in real economic prerequisites – increasing of the volume of the harvested industrial roundwood per capita on 40% (from existing 0,17 $m^3$to forecasting 0,25m^3), increasing of the volume of the produced particle board per 1000 person on 30% (from existing 35 m^3 to forecasting 45 m^3) and increasing of the number of enterprises in furniture manufacturing per 1 million inhabitants on 100 % (from existing 34 units to forecasting 68 units) will lead to final increasing of furniture turnover approximately in 4 times (from existing 15 EUR/person to forecasting 61 EUR/person). In our Ukrainian example values of such factors as average number of employees per enterprise in the national scale, GDP per capita and volume of the produced fibreboards per 1000 person were unchangeable because of economic difficulties of such changing providing.

Conclusions. Based on the results given in article it is possible to formulate the following conclusions. Furniture industry of Georgia is the most dynamic manufacturing that we can explain by vital economic reforms in this country. In return it can consider furniture industries of Ukraine and Moldova as very weak and such that need considerable improving.

1. In contradistinction to ENP countries, it can characterize furniture industry of Poland as more sustainable and more advanced branch (taking into account labor productivity, number of enterprises).
2. Number of the furniture enterprises per 1 million of inhabitants in ENP countries is much less than in Poland and in order to change this unfavourable situation it is necessary to carry out considerable improving in regard to availability of forest resources and ease of doing business.
3. It will be reasonable to consider furniture manufacturing in ENP countries as very perspective ones taking into account all favourable factors such as forest resources, economic feasibility, regional importance etc. and there are some indexes increasing which it is possible to step up development of the furniture industry (timber harvesting, particle boards manufacturing, fiber boards manufacturing).
4. Economic growing of furniture manufacturing in ENP countries has some challenges in regard to sustainable development since it does not into consideration environmental factors.

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Меблева промисловість в країнах Східної Європи: виклики і можливості для сталого розвитку

Представлено результати досліджень, які проведені для меблевої промисловості. Дослідження базується на порівнянні меблевої промисловості для трьох країн Східного Партнерства (Україна, Молдова і Грузія) з однієї сторони і меблевої промисловості Польщі та Австрії з іншої. В процесі дослідження автори даної статті: а) провели аналіз розвитку меблевої промисловості за період з 2008 по 2012 рік в країнах, що досліджуються, на основі абсолютних показників; б) провели порівняльний аналіз за 2012 рік на основі основних параметрів для меблевої промисловості перерахованих вище країн на основі відносних показників; в)розробили регресійну, яка визначає залежність такого дуже важливого параметра, як оборот на душу населення в меблевій промисловості відтаких показників - кількість підприємств у виробництві меблів на 1 мільйон жителів, середнє число працівників на підприємстві в національному масштабі, ВВП на душу населення, обсяг виробництва круглих лісоматеріалів на душу населення, обсяг виробництва волокнистих плит середньої щільності на 1000 осіб, обсяг виробництва стружковихплит на 1000 осіб. В результаті проведених досліджень ідентифіковано основні проблеми та можливості сталого виробництва для меблевої промисловості в Східній Європі.

Ключові слова: меблева промисловість, порівняльний аналіз, модель регресії, країни СЄП.

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RESOURCE EFFICIENCY AND RAW MATERIAL USE IN WOOD-WORKING INDUSTRIES IN EASTERN EUROPE: CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE PRODUCTION

The paper presents the results of research performed for forest sectors. The present researching is based on the comparison of the forest sectors three ENP countries (Ukraine, Moldova and Georgia) in the one hand and Polish forest sector from the other hand. In the process of the researching was determined and analyzed the main economic parameters of the forest sectors, the forest resources of the forest sectors for mentioned above countries, the contribution of these forest sectors to national GDP. As a result it has been identified the following challenges of the sustainable production for woodworking industry in Eastern Europe: economic power of the forest sectors in Eastern Europe shifted towards forestry; forest sectors in Eastern Europe differ by very poor productivity; there are very few enterprises in forest sectors of ENP countries comparing with EU countries because of complicity of doing business here; forest sectors of ENP countries produce much less products in in turnover terms; forest sector's share in ENP countries does not exceed level of 2 % from national GDP and there is tendency to constant decreasing of this share.

Keywords: forest sector; turnover; number of enterprises; number of employees; ENP countries; forest resourses; main challenges and opportunities; sustainable development.

Introduction. Wood is remarkable material since there are at least four extraordinary properties (so-called 4-R properties) of wood as a unique material [1-14]:

- wood is renewable material;
- wood is reused material;
- wood is recycled material;
- wood is refined material.

Some branches which have deal with wood it is possible to unite into forest sector which we can consider as a very important sector because it offers a simple way to reduce the CO_2 emissions that are the main cause of Climate Change, through:

- the carbon sink effect of the forests;
- the carbon storage effect of wood products;
- substitution of carbon-intensive materials.

ENP eastern countries hold considerable, yet less developed forest resources with a comparatively average lower land use pressure than in Western Europe (in total 15 million ha). A constantly growing demand for wood raw materials in European markets (2010: 0.8 billion m^3, 2020: 1,1 billion m^3, increase by +38%) leads to higher raw material imports and growing pressure on forests holding substantial, unexploited wood resources in neighboring Eastern Europe. The main challenge here is to support the development of sustainable management regimes of the abundant resource.

The wood-based industries, emerging anew in post-socialist economies, play a key role in this context, as they could develop an even stronger impact on regional production, employment and value adding -on the basis of regional natural resources. As such, the ENP region is currently gaining in importance as a raw material supplier with many downsides of a strategic new market for foreign investors (e.g. illegal logging and timber trade, offshoring of production, cut-throat competition, corruption, etc.).

Wood manufacturing is shaped by a large number of SMEs, mostly lacking proper organizational structures and staff to implement efficiency measures. Improvements are however urgent, because this SME-dominated sector consumes huge amounts of raw material per employee, and in total (ENP eastern countries' round wood consumption: 10 million m^3/y; total forest products: 20 million m^3/y).

The forestry and woodworking sector in ENP eastern countries faces major societal challenges (the unsustainable use of forest resources and wood materials), but shows decisive opportunities for improvement of the current state (increase of raw material efficiency and technological upgrading). And therefore it is very important in our point of view to identify the main chalenges of the sustainable production for woodworking industry in Eastern Europe.

Odjective. The main objectives of the present research were the following:

- to determine and to analyze the main economic parameters of the forest sectors for such countries as Ukraine, Moldova, Georgia and Poland;
- to determine and to analyze the forest resources of the forest sectors for mentioned above countries;
- to determine and to analyze the contribution of these forest sectors to national GDP.

Methods. For researching we use definition „forest sector". In such structure we decided to include four branches (subindustries) which have deal mostly with solid wood which we are considering as material that differs by very important economic, social and ecological mining: forestry, woodworking industry, furniture manufacturing, carpentry and joinery. The view of one large forest sector was put forward by the European Union to promote a common strategy for sustainable development of one of its largest industrial sectors. The main idea in this connection was nominally to unite the main industries or subindustries in one sector regarding decisive significance such resource as "forest" to derive valuable conclusions/ideas/measures for guaranteeing of sustainable development.

The present researching is based on the comparison of the forest sectors three ENP countries (Ukraine, Moldova and Georgia) in the one hand and Polish forest sector from the other hand. This "country choice" was motivated by the following reasons: Ukraine, Moldova and Georgia are ones of the most important in economic terms representatives of Eastern Partnership; Ukraine, Moldova and Georgia declare their commitments to the European way of development and it is important to evaluate their "forest possibilities" at the beginning of this way; Poland is a country which passed the way from country of socialist camp to the one of the EU leader; there are a lot of similarities between forest sectors of Ukraine and Poland; there are some similarities between forest sectors of Moldova and Georgia.

As the main parameters for any forest sector identifying we used the following:

- overall turnover; number of enterprises;
- number of employees.

The present researching is conducted for the five-year's time period beginning from 2008 and finishing 2012 but the main comparing are made for 2012.

The forest recourse we characterized by the following indexes: square of the forest land, overall timber stock, forest land percentage, procurement of merchantable wood and others value of which it is possible to derive from mentioned above with help of some additional ones.

Results and discussion. The obtained results in regards to three main parameters of the national forest sectors (turnover, number of enterprises and number of employees) are presented in Table 1. In order to analyze effectiveness of the forest resource for the different national sectors it has been used ten main indexes presented in Table 2. Additionally it has been determined these forest sector's shares to the overall turnover, to the overall number of employees and to the overall GDP that are presented in Tab. 3.

Table 1. Main parameters of the national forest sectors in 2012

Main parameters of the national forest sector	Name of the "forest" subindustry				Totally for national forest sector
	Forestry (02)	Woodworking industry (20)	Furniture manufacturing (36.1)	Carpentry (45.22) + Joinery (45.42)	
Ukraine					
Turnover, bil. UAH	6,1	10,3	7,2	0,82	24,42
Number of enterprises, units	991	3128	1548	601	6268
Number of employees, ths. persons	66,2	43,1	38,5	3,91	151,71
Moldova					
Turnover, bil. MDL	0,215	0,223	0,69	0,527	1,655
Number of enterprises, units	27	302	370	77	776
Number of employees, ths. persons	3,75	1,4	2,7	0,95	8,8
Georgia					
Turnover, bil. EUR	6,91	43,59	42,76	-	93,26
Number of enterprises, units	78	213	387	-	678
Number of employees, ths. persons	4,91	1,867	2,650	-	5,008
Poland					
Turnover, bil. PLN	9,32	29,56	28,79	-	67,67
Number of enterprises, units	19190	35597	27047	-	82194
Number of employees, ths. persons	31,1	101,5	138,6	-	271,2

Table 2. Some indexes which determine forest resources of the national forest sectors (2012)

Index's name	Index's value			
	Ukraine	Moldova	Georgia	Poland
Square of the forest land, mil Ha	10,80	0,37	2,82	9,40
Overall timber stock, bil m^3	1,80	0,05	0,45	2,40
Forest land percentage, %	15,70	12,70	40,50	30,00
Timber stock per enterprise, ths m^3/unit	287,17	57,99	670,35	29,20
Turnover per timber stock, EUR/m^3	1,31	2,29	0,21	6,88
Turnover per procurement of merchantable wood, EUR/m^3	134,30	210,11	208,40	445,86
Procurement of merchantable wood, ths m^3	17506,7	490,0	447,5	37045,0
Timber stock per inhabitant,m^3/person	39,09	12,50	103,30	62,83
Population, mil persons	46,05	3,60	4,40	38,20
Square of the forest land per inhabitant, Ha/person	0,23	0,10	0,64	0,25

Table 3. Some parameters of the relative ranking for the national forest sectors (2012)

Index's name	Index's value			
	Ukraine	Moldova	Georgia	Poland
Forest sector's share to the overall turnover, %	1,8	3,47	1,4	5,0
Forest sector's share to the overall number of employees, %	6,6	12,1	1,0	9,0
Rank by turnover share	9	10	10	8
Forest sector's share to the overall GDP, %	1,68	1,88	0,90	1,60

Structure of the forest sectors in turnover, number of enterprises and number of employees terms for such countries as Ukraine, Moldova, Georgia and Poland are presented in Fig.1…Fig.3. As shown in these figures, structure of the forest sectors is determined by share of different branches within the framework of these forest sectors. Among these subindustries we used the following ones: forestry, woodworking industry, furniture manufacturing and carpentry (Fig.1…Fig.3).

Analyzing structure of the forest sectors in turnover terms it is possible to point out that in Ukraine we have the largest share of the forestry in overall forest sector and it makes up 25 % (Fig. 1). As shown in Fig.3 in Ukraine the largest number of employees works in forestry. In our opinion two last facts allow to conclude that in Ukraine we can observe "too much attention" to forestry comparing with other subindustries and other countries. In the same time in Poland and in Georgia such very important branches which provide secondary timber treatment and therefore can provide more value added as woodworking industry and furniture manufacturing make up together approximately 90 % (Fig.1…Fig.3). Comparing these shares with Ukrainian and Moldavian respective parameters we can observe much less such shares. For instance, taking into account number of employees terms (Fig. 2), it turns out that summing share of number of employees in woodworking industry and furniture manufacturing in Ukraine makes up only 54 % and in Moldova respective index is equal to 47%.

As a result, in our point of view, forest sectors of Eastern Neighborhood Partnership need substantial improving since we can consider forestry in forest sector as raw material branch, some extract branch saying about industrial capacities (in fact, forestry has some other very important tasks as planting and saving of the timber stock using sustainable management rules) and therefore we should replace industrial development to the site of deeper treatment, towards development and growing of the secondary processing: woodworking industry, furniture manufacturing and carpentry. These changes will allow to increase economical effectiveness and number of employees. Using data from Table 1 it can determine so-called average enterprises for forest sectors of the different countries. In our opinion it is interesting to compare such indexes as average turnover for forest sector's enterprise (Fig. 4), average turnover per employee (Fig. 5) and average number of employees (Fig. 6). As shown in the Fig. 4, in 2012 the largest turnover per forest sector's enterprise we had in Ukraine while for other countries from our researching list average turnover approximately is two times less than in Ukraine.

As we can see in Fig. 5 average turnover per employee in Poland is approximately three times more than in three countries of Eastern Neighborhood Partnership but in Ukraine there is the largest number of employees for average forest sector's enterprise (Fig. 6). Analyzing these three figures we can conclude that the most effective employee works in Polish forest sector since in average such employee make production in three times more (in turnover terms) than in other countries (Fig. 5). It is very interesting that the most effective enterprise (in turnover terms) of the forest sector we have no in Poland as well since according our data the Ukrainian enterprise differs by the largest turnover (Fig. 4). And what is more, average Ukrainian enterprise has more employees than other forest sector's enterprises in Moldova, Georgia and Poland (Fig. 6). Of course there is some contradiction – the most economically powerful employee we have in Poland but the most powerful enterprise – in Ukraine. We can suggest some logical explanation for this phenomenon – we can assume that in Eastern Neighborhood Partnership countries and particularly in Ukraine there is considerable underestimation regarding number of enterprises and as consequence number of employees in its forest sector.

There are some reasons of such underestimation. Among them we can determine existing shadow sector in ENP countries, concealment of real number of employees and enterprises with purpose of real taxation avoiding. In order to draw some very important conclusions and to elaborate some recommendations for forest sectors improving we in the process of our researching made comparison for forest sectors of four countries determining four main parameters: turnover, number of enterprises and number of employees. It turned out that the most powerful forest sector we can assume the Polish forest sector by main parameters mentioned above. In 2012 turnover of the Polish forest sector made up 16,5 bil EUR while in Ukraine this index made up 2,35 bil EUR and respectively for Moldova and Georgia we have the same index – 0,1 bil EUR. There is similar picture in respect to number of employees (Table 1). In today's difficult social and economic conditions in Europe Union in regard to crisis manifestations we tend to consider number of employees as one of the most important index which depend from many different factors including number of enterprises.

As shown in Fig. 7 there is a huge difference between number of enterprises in Polish forest sector in the one hand and other forest sectors in the second one. In order to lead this data to a common denominator we should eliminate the influence of such factors as number of inhabitants and timber stock per inhabitant. In other words it is necessary to take into account in this case certain country's dimensions and existence of the forest resources. We can still observe a very large difference regarding number of enterprises even using such specific indicator as number of enterprises per million of inhabitants (Fig. 8). This difference (between Polish and other countries) approximately makes up more than a tenfold advantage in comparison to Ukraine, Moldova and Georgia. And we cannot explain this fact by the difference of forest resources availability since as shown in Fig. 9 Georgia has the largest index of timber stock per inhabitant. We tend to think that beside such problem as large share of the shadow sector within ENP countries' forest sectors there is some other one and maybe more important - complexity of doing business in the forest sectors of ENP countries.

In our opinion there are a lot of different conditions which complicate process of the enterprises creation in forest sectors such as availability of the timber in these countries, non-effectiveness of the state ownership in different areas of the forest sector, procedure of the timber resources sale and some others.

As shown in Fig. 10 and Fig. 11, Poland produces more products in its forest sector in turnover terms from 1 m^3 of procurement merchantable wood and from 1 m^3 of overall timber stock as well. In this regard we can consider Polish forest sector as the more productive in comparison to forest sectors of Ukraine, Moldova and Georgia.

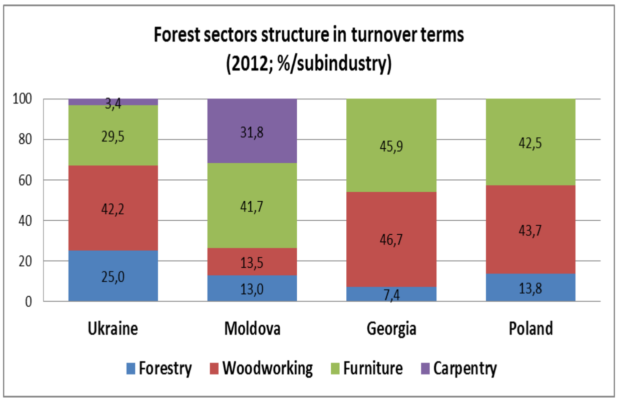

Fig. 1. Shares of the forest sector's subindustries for different countries in turnover terms

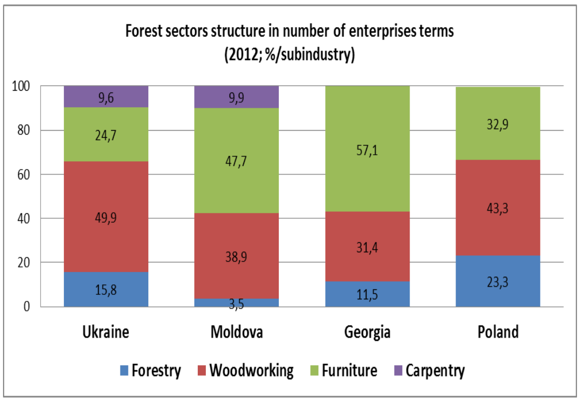

Fig. 2. Shares of the forest sector's subindustries for different countries in number of enterprises terms

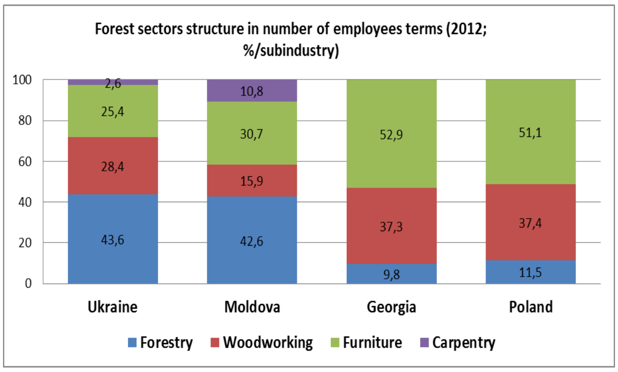

Fig. 3. Shares of the forest sector's subindustries for different countries in number of employees terms

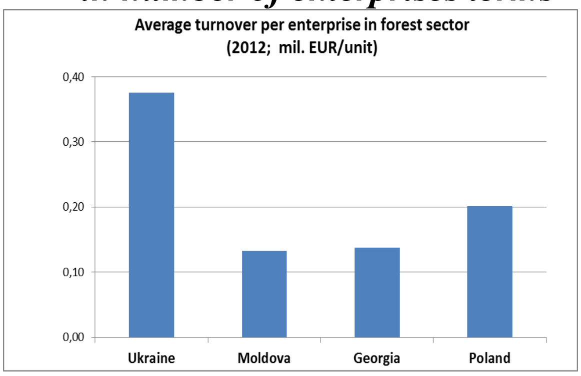

Fig. 4. Average turnover for forest sector's enterprise in different countries

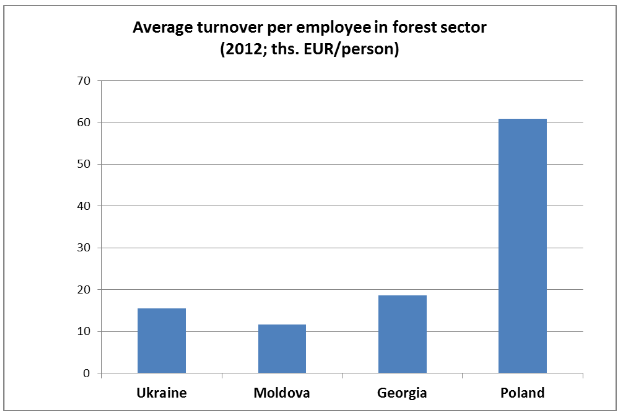

Fig. 5. Average turnover per employee of the forest sector's enterprise in different countries

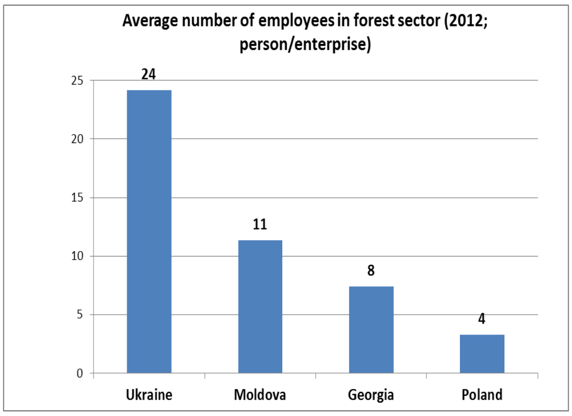

Fig. 6. Average number of employees of the forest sector's enterprise in different countries

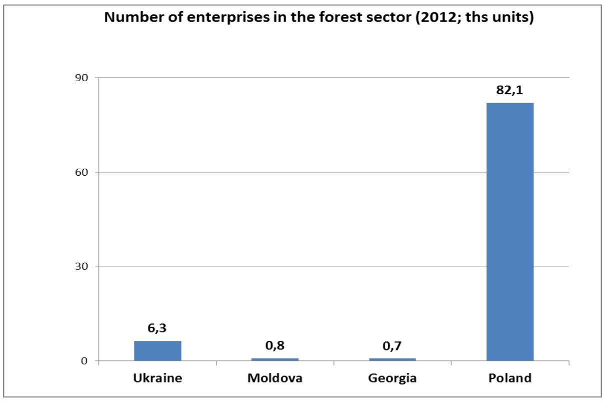

Fig. 7. Number of enterprises in forest sectors of different countries

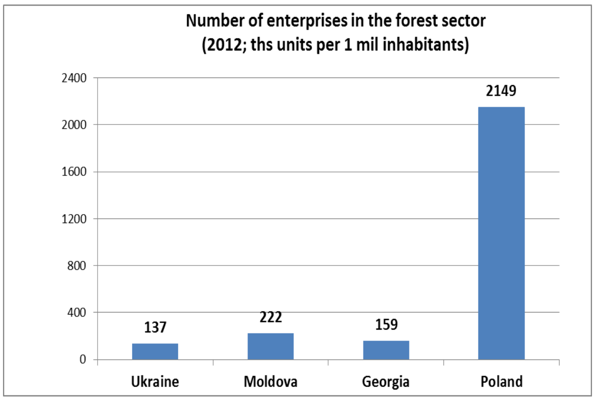

Fig. 8. Number of enterprises per million of inhabitants in forest sectors of different countries

Of course, there is considerable difference between price for forest sector's products in EU, particularly in Poland and in ENP countries but nevertheless we should derive value added from timber unit as much as possible because of exclusive ecological and economical mining of timber using sustainable development approach.

There is some fact in our researching which we can consider as a common disadvantage, as shortcoming using which we can characterize forest sectors of four countries from our searching list – forest sector's share does not exceed level of 2 % from national GDP (Fig. 12). And what is more, according our researching this share has tendency to constant decreasing, that we cannot consider as sustainability manifestation.

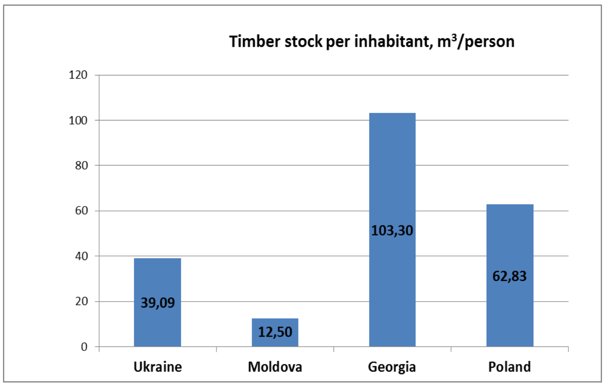

Fig. 9. Timber stock per inhabitant **in forest sectors of different countries**

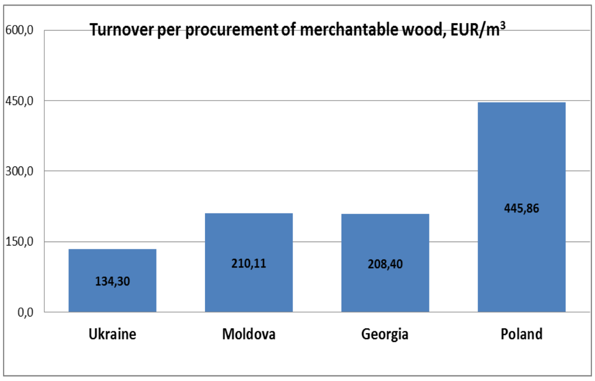

Fig. 10. Turnover per procurement of merchantable wood in forest sectors of different countries

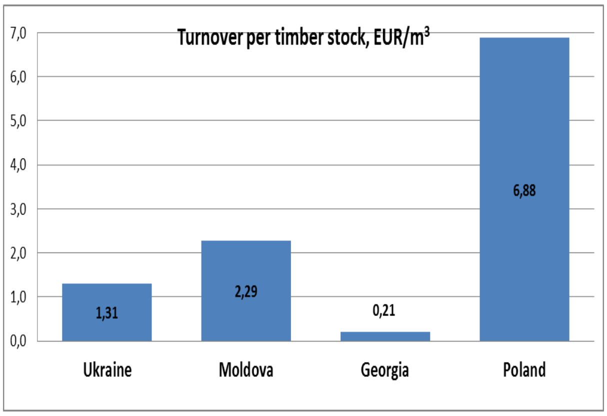

Fig. 11. Turnover per timber stock in forest sectors of different countries

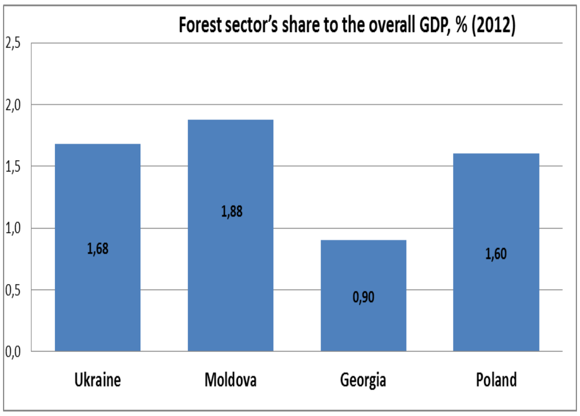

Fig. 12. Forest sector's share to overall GDP in different countries

Conclusions. As a result in the process of our researching we identify the following chalenges of the sustainable production for woodworking industry in Eastern Europe.

1. Economical power of the forest sectors in Eastern Europe shifted towards forestry while secondary processing differs by poorer capacities and this fact hamper comprehensive sustainable development of these forest sectors, cause very poor value added.
2. Forest sectors in Earsten Europe differ by very poor productivity, since in average, one employee produces much less than in EU and therefore forest sectors in ENP countries need considerable productivity improving through, for instance new technologies, new tools and eguipment, innovations and restructuring.
3. There are very few enterprises in forest sectors of ENP countries comparing with EU countries because of complicity of doing business here: availability of the timber in these countries, non-effectiveness of the state ownership in different areas of the forest sector, procedure of the timber resources sale.
4. Forest sectors of ENP countries produce much less products in in turnover terms from 1 m^3 of procurement merchantable wood and from 1 m^3 of overall timber stock as well and it is necessary considerable increasing of secondary treatment effectiveness.
5. Forest sector's share in ENP countries does not exceed level of 2 % from national GDP and there is tendency to constant decreasing of this share.

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Ресурсоефективність використання сировини у деревообробній промисловості Східної Європи: виклики і можливості для сталого розвитку

Представлено результати досліджень, які проведенні для лісового сектора. Дослідження базується на порівнянні лісових секторів трьох країн Східного партнерства (Україна, Молдова і Грузія) і лісового сектору Польщі. У процесі дослідження було визначено і проаналізовано основні економічні показники лісових секторів та лісових ресурсів для згаданих вище країн, проаналізовано внесок цих лісових секторів у ВВП країни. В результаті були визначені наступні проблеми сталого розвитку для деревообробної промисловості у Східній Європі: економічна міць лісового сектора в Східній Європі зміщена в бік лісового господарства; лісові сектори в країнах Східної Європи відрізняються дуже низькою продуктивністю; дуже малакількість підприємств в лісових секторах країн Східного Партнерства в порівнянні з країнами ЄС через складність ведення бізнесу; лісові сектори країн Східного партнерства виробляють набагато менше продуктів з обороту; частка лісового сектора в країнах Східного партнерства не перевищує рівень 2% від національного ВВП і є тенденція до постійного зменшення цієї частки.

Ключові слова: лісовий сектор; оборот; кількість підприємств; кількість працівників; країни СЄП; лісових ресурсів; основні проблеми та можливості; сталий розвиток.

UDC 674.04

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PREDICTION OF THE DURABILITY OF THERMOPLASTIC ADHESIVE PINE WOOD JOINTS

Abstract. Presented here are the results of predicting the durability of thermoplastic adhesive joints of pine wood by means of mathematical models. An analysis was made of the obtained results, on the basis of which it is established that with increasing the ambient temperature, the durability of thermoplastic polyvinyl acetate adhesive pine wood joints with the degree of load D4 decreases, and when the ambient humidity increases, the durability, by contrast, is slightly increasing.

Keywords: durability, adhesive joint, mathematical model, prediction, strength, humidity, temperature.

Topicality. Among the basic requirements that are imposed upon adhesive wood joints is ensuring adequate strength and durability. These requirements are interrelated and determine the quality and reliability of the product; this depends on the physical and mechanical properties of adhesives and materials to be glued, bonding process parameters, operating conditions, physical loading, etc. [1, 2]. Strength is an important characteristic of adhesive wood joints during operational service, but it does not offer a means of obtaining quantitative indicators of service time of glued products. It is durability that is the quantitative indicator of service time of any glued product. It is determined by the time of operation, duration or period of service life [3].

On the basis of experimental and theoretical studies, using simulation and mathematical modelling, we obtained a mathematical model to predict the durability of thermoplastic adhesive joints of oak wood [4, 5, 6, 7], which takes the following form:

$$\tau^{(i)} = \frac{1}{C^{(i)}} \cdot \ln\left(\frac{B^{(i)} \cdot \Delta W^{(i)}}{\sigma_{гран.} + A^{(i)} \cdot \Delta T^{(i)}} \right) \tag{1}$$

where $\Delta T^{(i)}$ is weighted average ambient temperature, °C; $\Delta W^{(i)}$ is weighted average ambient humidity, %; $\sigma_{гран.}$is ultimate strength of the joint; the parameters $A^{(i)}$, $B^{(i)}$,$C^{(i)}$ are dependent upon variations in the ambient humidity and temperature; 1 is the coefficient for wood species that takes into account theological , physical and chemical properties of oak wood. The coefficients for other wood species which would take into consideration their physical and mechanical characteristics had to be calculated. The calculation of the coefficients for some wood species was given by the author in his previous works [8]. Taking into account the coefficient for pine wood species, the mathematical model of durability prediction will take the form:

$$\tau^{(i)} = \frac{0{,}635}{C^{(i)}} \cdot \ln\left(\frac{B^{(i)} \cdot \Delta W^{(i)}}{\sigma_{гран.} + A^{(i)} \cdot \Delta T^{(i)}} \right) \tag{2}$$

The results of the studies. The proposed mathematical model allows predicting the durability of both cross-linked and uncross-linked thermoplastic polyvinyl acetate adhesive joints of pine wood. That is, by specifying the degree of load for an adhesive joint, the ambient humidity and temperature, it is possible to predict the durability for thermoplastic adhesive pine wood joints by non-destructive method. During prediction of the durability of adhesive joints, the ambient humidity and temperature were consistent with their weighted average values for a 3-year period of long-term experimental studies [9]. For example, Figs.1 and 2 show a graphical interpretation of the results of predicting the durability of thermoplastic polyvinyl acetate adhesive joints of pine wood obtained by means of mathematical modelling. As can be seen from these dependences (see Fig.1), at weighted average ambient temperature of 4.19 ^{0} C and weighted average humidity of 65.46% the durability is 687 days. In the case of increasing humidity to 93.91% at this temperature, the durability is increased to 787 days, i.e. by 100 days, or 12%. A similar pattern is observed for weighted average temperatures of 7.89 °C and 12.23 °C for which the durability is also increasing by an average of 100 days.

That is, with increasing humidity from 65% to 92%, the durability increases, on average, by 13% regardless of the operating temperature.

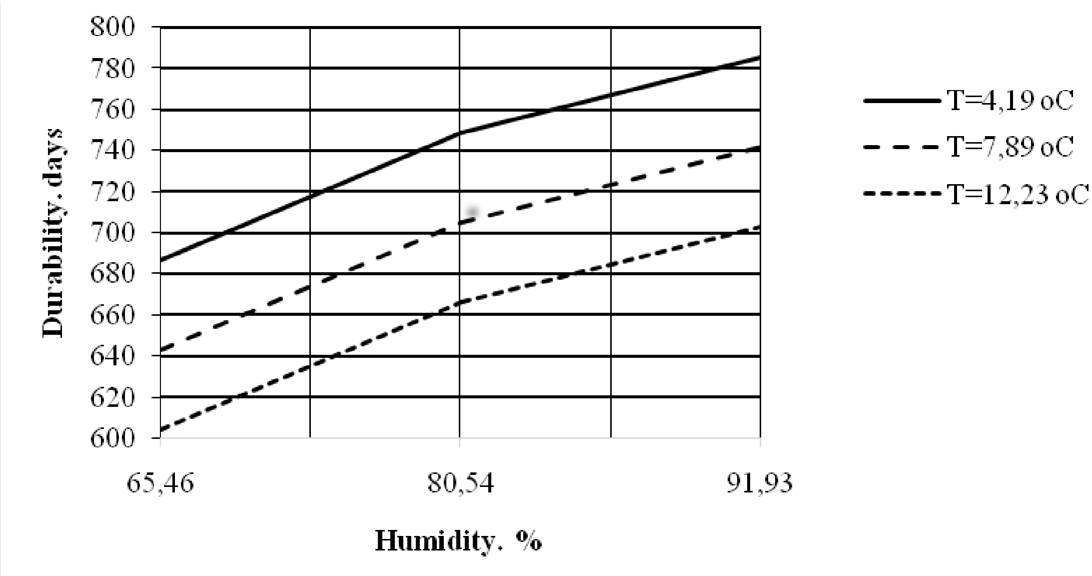

Fig.1. Prediction of the durability of adhesive pine wood joints bonded with cross-linked adhesive with the degree of load D4 depending on humidity changes

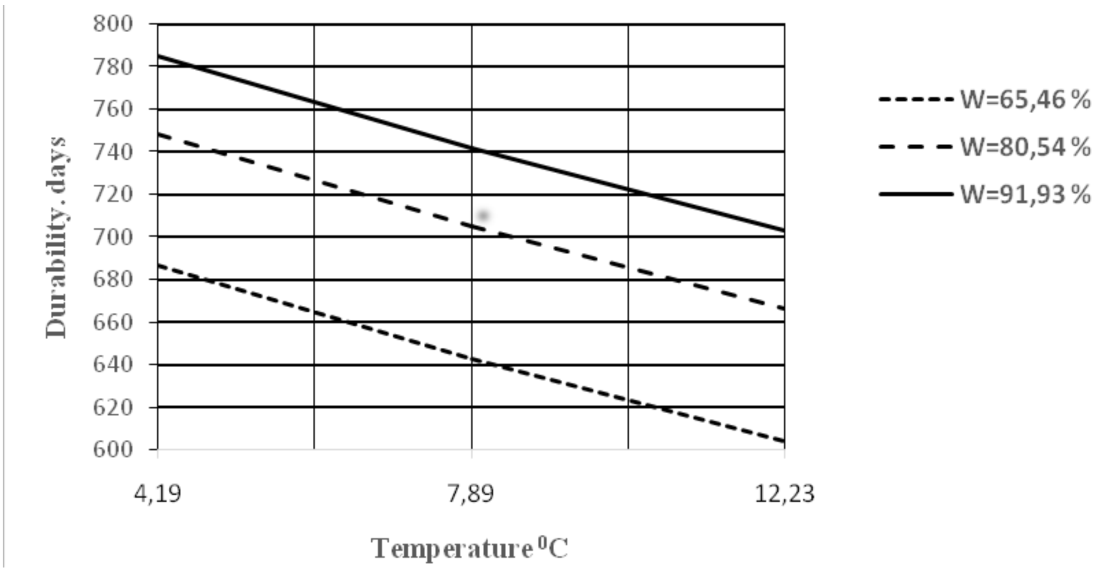

Fig. 2. Prediction of the durability of adhesive pine wood joints bonded with cross-linked adhesive with the degree of load D4 depending on temperature changes

A similar pattern is observed for weighted average temperatures of 7.89 °C and 12.23 °C for which the durability is also increasing by an average of 100 days. That is, with increasing humidity from 65% to 92%, the durability increases, on average, by 13% regardless of the operating temperature.

The effect of temperature on the durability (see Fig.2) shows that for the weighted average temperature of +4.19 °C and humidity of 65.46%, the durability is 685 days, while at a temperature of 12.23 °C the durability is reduced to 605 days.

The decrease in durability, on average, by 80 days with temperature change from 4.19 to 12.23 °C, also occurs at humidity values of 80.54 and 91.93%, but with higher durability values (for example, to 781 days at a humidity of 91.93%). Thus, a rise in temperature, on average, by 1 °C shortens the life of product by 10 days, while an increase in humidity by 1% increases the service life by about 3 days.

Fig. 3 shows the predicted durability of adhesive pine wood joints glued with thermoplastic adhesives depending on variation in weighted average temperature at various ambient humidity levels.

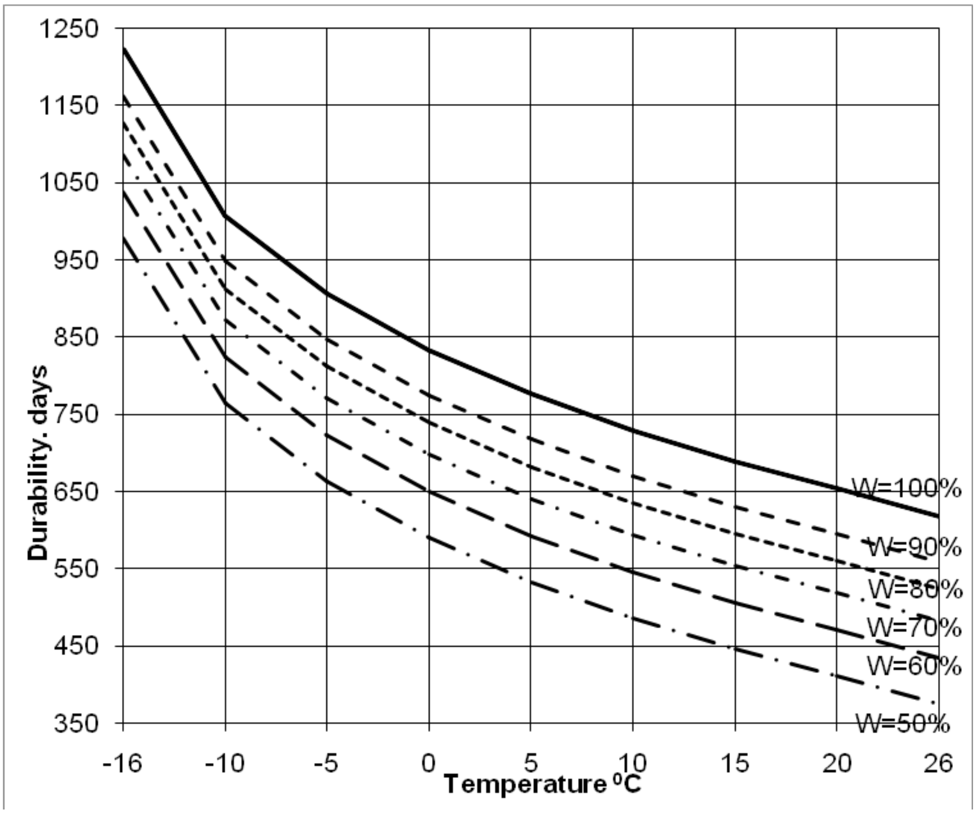

Fig.3. Prediction of the durability of adhesive pine wood joints glued with cross-linked adhesive at the degree of load D4 depending on weighted average temperature changes at various ambient humidity levels

Fig. 4 shows predicted durability of adhesive pine wood joints glued with cross-linked adhesives with load D4 depending on changes in weighted average humidity for various operating temperatures.

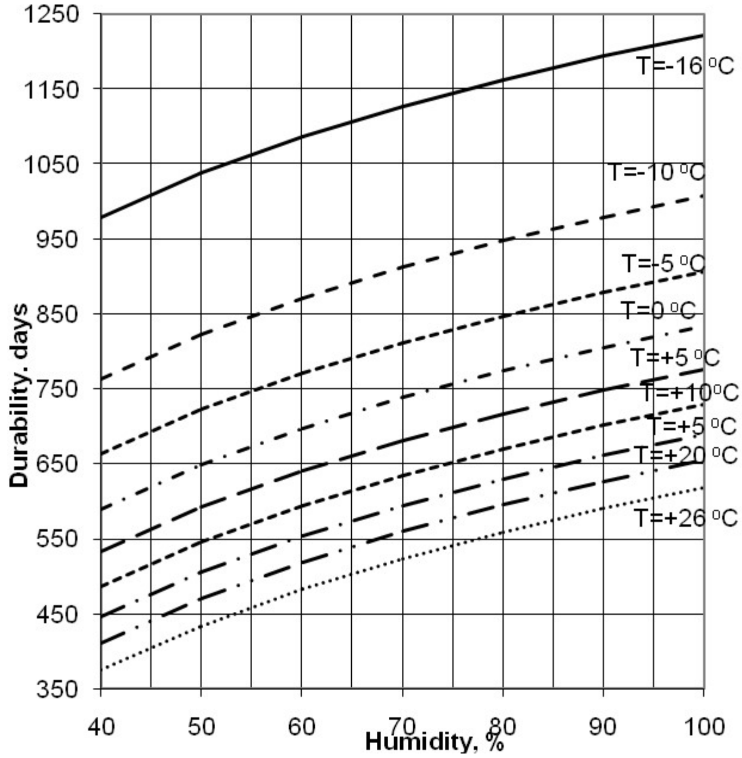

Fig. 4. Prediction of the durability of adhesive pine wood joints glued with cross-linked adhesives with the degree of load D4 depending on humidity and temperature changes

Similar results of prediction of the durability can be obtained using a mathematical model for pine wood glued with uncross-linked thermoplastic adhesives. Thus, an increase in ambient temperature results in reduced durability of thermoplastic polyvinyl acetate adhesive pine wood joints with the degree of load D4, while an increase in ambient humidity, on the contrary, leads to a slight increase in durability of such adhesive joints.

Conclusions. By using mathematical modeling, prediction was implemented for durability of thermoplastic adhesive pine wood joints. Analyzed was the effect of the ambient temperature and humidity on the durability of these adhesive wood joints. Identified were quantitative indicators of durability of thermoplastic polyvinyl acetate adhesive joints of pine wood depending on the operating conditions.

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Прогнозування довговічності термопластичних клейових з'єднань деревини сосни

Наведено результати прогнозування довговічності термопластичних клейових з'єднань деревини сосни за допомогою математичної моделі. Здійснено аналіз отриманих результатів, на основі якого встановлено, що при підвищені температури навколишнього середовища, довговічність термопластичних полівінілацетатних клейових з'єднань деревини сосни із ступенем навантаження D4 - зменшується. А при підвищені вологості навколишнього середовища навпаки, довговічність незначно зростає.

Ключові слова: довговічність, клейове з'єднання, математична модель, прогнозування, міцність, вологість, температура.

UDC 684.4.059.4
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THE PECULIARITIES OF DISPERSION PAINT-AND-LACQUER MATERIAL FLOW IN THE GAP OF ROLLER MACHINE

Abstract. The behaviour of paint-and-lacquer material in the application zone of roller machine has been examined using the hydrodynamic analysis of viscous-plastic fluid flow. The obtained dependences are needed to substantiate the technological parameters for the thin-layer application of water-dispersion paint-and-lacquer coating.

Key words: water-dispersion material, roller machine, viscous-plastic fluid, roller, gap, technological parameters.

Introduction and relevance of the problem. The most labor-intensive and important stage of the production process in woodworking is finishing of products. In recent years, due to aggravation of energy crisis and adoption of more stringent laws on environmental protection, there have been significant changes in the range of paint-and-lacquer materials (PLM).The furniture industry is shifting to thin-layer finishing as the most economic alone since it provides the reduction in PLM consumption rate, labor intensity and cost price. Among the materials for thin-layer finishing, water-dispersion materials currently occupy an important place.

Thin-layer application of PLM calls for the widespread use of roller equipment that provides the application with a minimal consumption of the material.

An analysis of the studies and publications.Water-dispersion materials belong to the group of soliquids of hydrosols, but if the solid particles are polymers and the medium is water,suchhydrosols are called latexes. Latexes are obtained by emulsion polymerization of monomer in water. Thus obtained latex is but one of many ingredients of the complex system which, apart from latex,also includes pigments, protective colloids, emulsifiers, antifoam generators, stabilizers and sometimes plasticizers.

Protective colloid increases the viscosity of the dispersion medium and thus contributes to the stabilization of the dispersed particles. It also influences the extent of viscosity dependence on shear rate. This leads to the fact that the viscosity significantly increases at low shear rate, the material does not drip from the surface, does not sag; however, in case of considerably high shear rate, the latex flows easily in the process of applying the material. Stabilizing system must be chosen so that the destruction of the latex in the process of coating formation occurs at the right time. In the process of applying the latex, the water should form a continuous phase.

When the water evaporates, the latex is destroyed, that is the water becomes the disperse phase, distributed in a continuous phase of the polymer. The destruction of the latex should take place only after the film application on the substratum.

Presentation of the basic material. The latexes are characterized both by yield point $\tau_т$ and a variable plastic viscosity η. Depending on the shear rate dv/dy, their flow can be modeled by the Shvedov-Bingham rheological equation [1]

$$\tau = \tau_т + (dv/dy) \qquad (1)$$

where τ is shear stress.

Schematic application of PLM on the roller machine in the zone of the coating formation is shown in Fig. 1. Hydrodynamic analysis of the viscous-plastic fluid flow [2] makes it possible to identify the essence of the phenomena occurring in the deformation zone as well as the general character of the kinematics and dynamics of flow. It turns out that the fluid flow is heterogeneous and consists of two zones of viscous flow within the surfaces of the paintwork panel and roller and the plastic core in the middle part, where the shear stress exceeds the yield point.

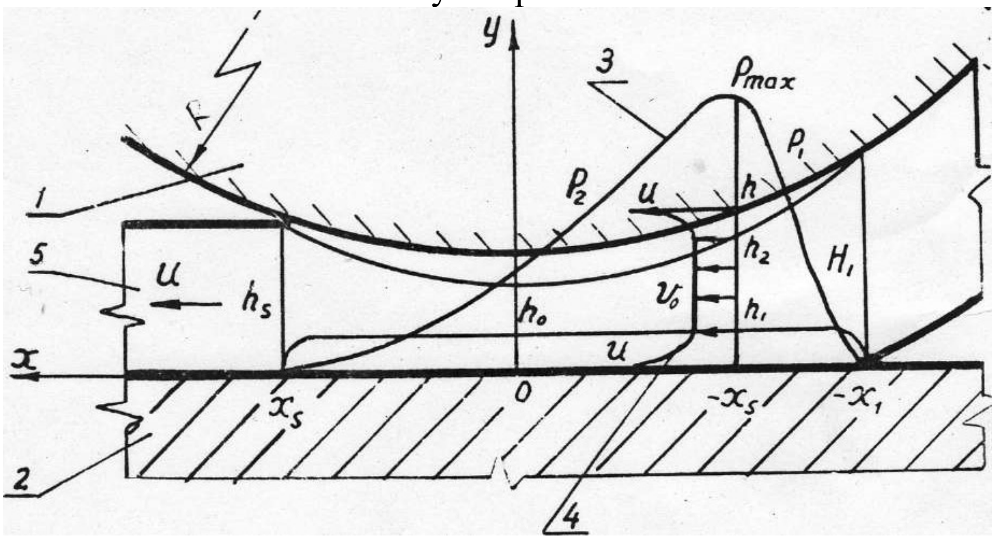

Fig. 1. Diagram of the coating formation on the roller machine
1 - applicator roller; 2 - substratum; 3 – pressure distribution P(x);
4-velocity distribution of material movement

Equations for flow velocities:

- near the surface of the paintwork panel

$$v_1 = u - \frac{2h_1 y - y^2}{2\eta}\frac{dp}{dx}\ ; \tag{2}$$

- near the surface of the roller

$$v_2 = u - \frac{(h^2 - y^2) - 2h_2(h - y)}{2\eta}\frac{dp}{dx}\ . \tag{3}$$

On the surface of the roller and the paintwork panel, flow velocity is maximum and is equal to **u**.

- for plastic core $$v_0 = u - \frac{(h - h_2)^2}{2\eta}\frac{dp}{dx}\ , \tag{4}$$

where u is the feed rate of the paintwork panel and the peripheral speed of the applicator roller**;** $\mathbf{h_1}$ and $\mathbf{h_2}$ are the ordinates of viscosity zone**; h** is theheight of deformation zone; **y** is the variable ordinate; **dp/dx** is the pressure gradient of the fluid.

Specific consumption of material is defined as the product of the height of the cross-section by the flow velocity through the cross-section

$$q = \int_{-x_1}^{-x_s} p_1 dx + \int_{-x_1}^{-x_s} p_2 dx\ \ , \tag{5}$$

or

$$q = uh - \frac{1}{\eta}\frac{dp}{dx}\left(\frac{2}{3}h_1^3 + \frac{h_1^2(h_2 - h_1}{2}\right)\ . \tag{6}$$

During the movement of material through the area of deformation, specific pressure ranges from **0**in the cross-section of the entrance to the gap$(-x_1)$ to a maximum value in the cross-<u>section</u>$(-x_s)$ and again decreases to **0** in the section $(-x_s)$**).**

The distribution of the specific pressure in the deformation region is asymmetrical, so the pressure is determined separately for areas of accelerated motion of the material **dp₁/dx** and its deceleration **dp₂/dx.**

The interaction of forces $\mathbf{p_1}$ and $\mathbf{p_2}$ creates a separating force **F**, which must be compensated by the pressure force of the rollers

$$F = \int_{-x_1}^{-x_s} p_1 dx + \int_{-x_1}^{-x_s} p_2 dx \,. \tag{7}$$

Conclusions. The analysis of obtained equations and their experimental verification will allow creation of preconditions for substantiation of parameters of roller machines when applying water-disperse paint-and-lacquer coatings.

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Особливості течії дисперсійних лакофарбових матеріалів у зазорі вальцевого верстату

Проаналізованоповедінку лакофарбового матеріалуу зоні нанесення вальцевого верстату, з використанням гідродинамічного аналізу течії в'язкопластичної рідини. Отримано залежності, необхідні для обґрунтування технологічних параметрів при тонкошаровому нанесенні водно-дисперсійних лакофарбових покриттів.

Ключові слова: воднодисперсійний матеріал, вальцевий верстат, в’язкопластична рідина, валець, зазор, технологічні параметри.

UDC 621.86.065

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CALCULATION FEATURES OF VARIABLES PROCESS LOADS ACTING ON THE CABLE TIMBERTRANSPORTING PLANTS DRIVE

Improved the theoretical methods of calculation of technological tension in cable timber transporting plants drives taking into account the duration of the technological cycle of the plant, multilayer cable winding on driving drums, cable tension force that varies and depends on the working mode of plant and operating parameters.

Keywords: cable timber transporting plant drive, technological loads, haul-lifting cable, cable tension force.

Introduction. About one-third of forests in Ukraine are in the mountainous and difficult terrain. The experience of logging in mountains in our country and abroad showed that cable timber transporting plants are an effective means of primary timber transport that best correspond modern environmental and industrial requirements [1, 5, 6, 7]. The creation of new and improvement of existing methods of calculating the basic structural elements of cable timber transporting plants is an actual task.

Formulation of the problem. According to the principle of work and the quantity of cables the majority of cable plants with carrying cable can be represented by a few basic schematic (Fig. 1), that are inherent to the plants with mobile and stationary drives [1, 5, 6, 7]. Hauling cable can be simultaneously the lifting one (Fig. 1, a) [5,6,7].

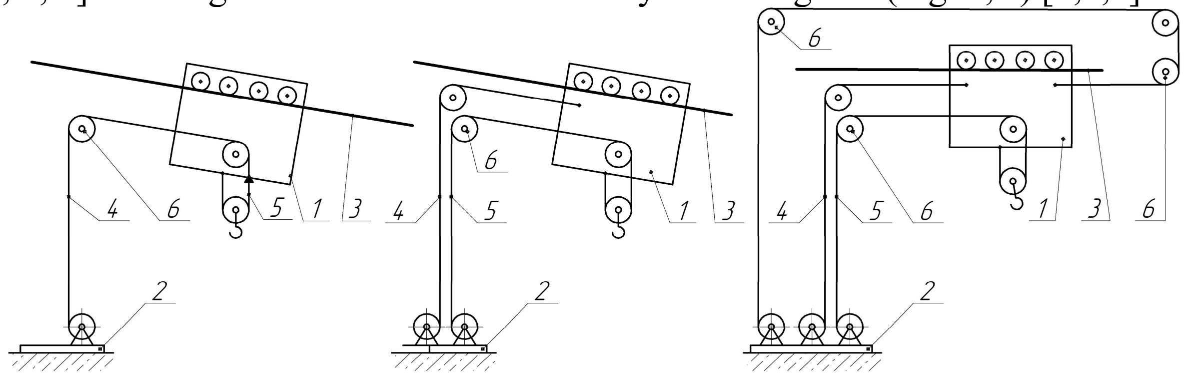


Fig. 1. Schematic diagrams of timbertransporting plants equipped with carrying cable and one- (a), two- (b) and threedrum (c) drives: 1 – carriage; 2 – drive; 3 – carrying cable; 4 – hauling cable; 5 – lifting cable; 6 – bypass blocks.

A typical work cycle of cable systems (Fig. 1) includes the following stages:

- cable slack removing (characterized by a progressive increase in cable tension force to a value equal to the weight of cargo);
- cargo lifting;
- cargo and freight carriage locking;
- the transfer of cargo carriage and cargo along carrying cable.

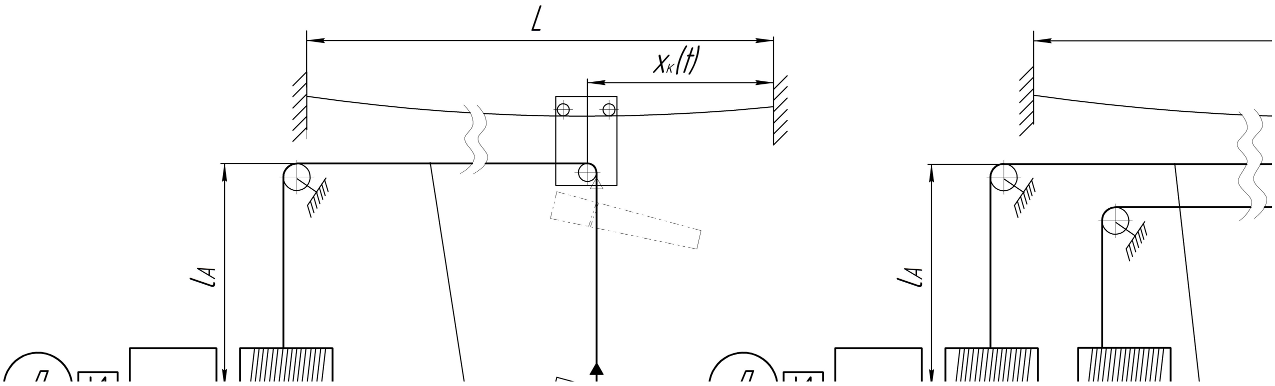
Besides mensioned the above stages, there may be auxiliary stages such as: moving and lowering empty lifting devices to a place of load coupling and pulling of wood to the line of carrying cable.

The drive is complex and significant structural element of cable timbertransporting plant, which determines its reliability and range of possible technological operations. To study the internal loads arising in drive elements, it is necessary toconsider the value and nature of external technical efforts, acting on the driving drums.

The study of complex technical systems, which are drives of cable transport systems requires simplification of fundamental schemes and consideration only the common essential features. In onedrum cable plant (Figure 1, a), all the operations are performed by haul-lifting cable (load lifting, its locking and moving). In two- or threedrum units (Fig. 1, b, c) load is mowed by hauling cable. But simultaneous switch of hauling and lifting cable drums is rarely used (especially when performing installation and support operations) [1, 5, 7]. Therefore, to study the work of one- and twodrum cable plant drives cable installations (Figure 1, a and 1, b) can be used onedrum schematic diagram (Figure 2, a), and to study threedrum drive - twodrum schematic diagram (Fig. 2, b).

In the working process of cable plant drive cable tension force varies and depends on the working mode of plant and many operating parameters (rope winding speed, placement coordinate of cargo carriage in passage, lifting height, etc.).

In the analyzed research [1-8], that are focused on, taking into account the impact of these factors is limited and mainly relates solving specific problems, such as determining the tension forces during cargo lifting [8] or moving cargo carriage [5]. In the existing publications generalized analysis and systematization of theoretical studies of variation of haul-lifting cable tension force and changes of rotation resistance moment at driving drums of the cable timbertransporting plants are not done. The impact of multilayer cable winding on the value of technological efforts is not taken into account. Therefore, these objectives remain valid. The aim of this study is to determine the theoretical time dependance of the technological resistance moment for the driving drum of cable timbertransporting plant, taking into account the duration of the technological cycle of the plant, as well as multilayer cable winding on driving drums.



a) b)

Fig. 2. Fundamental diagrams of one- (a) and twodrum (b) timbertransporting plant drives equipped with carrying cable: 1 – engine; 2 – coupling; 3 – mechanical transmission; 4 – drive drum of working motion; 5 – haul-lifting cable; 6 – load; 7 – reverce cable; 8 – reverse drive drum; L – the length of the cable plant; $x_K(t)$ – cargo carriage coordinate in a span; l_A – the length of the reserve cable.

The study ofthe influence of the tension force in haul-lifting cable. The expression to calculate the moment of technological resistance forces can be written as follows:

$$M_{CO}(t) = S(t) \cdot r_H(t), \tag{1}$$

where $S(t)$ – haul-lifting cable tension force (technological efforts); $r_H(t)$ – the radius of the drum with a wounded cable.

Tension in haul-lifting cable when lifting cargo can be defined as follows [1, 8]:

$$S(t) = S_2 = Q + \frac{C_{3B}}{l_0} \cdot \frac{\mathrm{v}}{\beta_1} e^{\alpha t} \left\{ \left[\left(1 - \frac{\alpha^2}{\beta_1^2}\right) \cdot \left(1 - \frac{\alpha t}{2}\right) + \alpha^2 t^2 \right] \cdot \sin \beta_1 t + \right. \\ \left. + \left[\left(\beta_1^2 - \alpha^2\right) t + 2\alpha \right] \frac{\alpha t}{2\beta_1} \cos \beta_1 t \right\}, \tag{2}$$

where: S_2 – tension in haul-lifting cable when lifting cargo; $l_0 = H_G + \sum_{i=1}^{n} l_{0i}$ – initial cable length (load at the time of lift beginning); H_G – height of cargo lifting; Q – cargo weight; l_{0i} – length of hauling cable on i-section; v – speed of cargo lifting, which with sufficient accuracy can be calculated as a linear cable winding speed; α, β_1 – characteristic equation coefficients; C_{3B} – conditional reduced longitudinal stiffness of the cable system during cargo lifting.

Conditional reduced longitudinal stiffness of the cable system during cargo lifting [1, 8]:

$$C_{3B} = \frac{E_K A_K}{1 + \dfrac{\lambda E_K A_K}{l_0}}, \tag{3}$$

where $\lambda = \lambda_1(1-\sin\gamma_1) + \lambda_2\cos\gamma_1 + \frac{q_H{}^2}{12Q^3}\sum_{i=1}^{n}\frac{a_i^3}{\cos\gamma_i} + \lambda_Л + \sum_{i=1}^{n}\lambda_{\delta i}$ – reduced compliance of the cable system; $\lambda_1 = \frac{T_1 - \frac{T_1 - T_0}{Q}\left(Q + G + \frac{q_H \cdot L}{2\cos\gamma}\right)}{T_1^2\cos\gamma}\cdot\frac{a(L-a)}{L}$ – compliance of carrying cable in the transverse direction; $E_K A_K$ – longitudinal haul-lifting cable rigidity; E_K – elastic module of haul-lifting cable; A_K – the total cross-sectional area of the cable wires; q_H – weight per meter of carrying cable; γ_1 – slope angle of the span chord to the horizon; G – the weight of the carriage; $T_1 = T_0 + r_H S$ – tension of the carrying cable when $(S+G)$; $T_2 = T_0 + r_H(S+\Delta S)$ – tension of the carrying cable when $(S+G+\Delta S)$; T_0 – mounting tension of the carrying cable loaded by the empty carriage; λ_2 – compliance of carrying cable in the longitudinal direction; $\lambda_Л$ – drive compliance; a_i, γ_i – horizontal projection and the slope angle to the horizont of i-section of the hauling cable; L – the total length of the span. Taking into account the results [8], the expression to determine the tension force in a cable at the time of locking is as follows:

$$S(t) = S_З = S_{З0} + \frac{C_{ЗВ}{}^{/}}{l_0^{/}}\cdot \mathrm{v}\cdot\left[t - t_{0C}\right], \tag{4}$$

where t_{0C} – auxiliary variable that takes into account the time of the initial locking period; $S_З$ – tension in haul-lifting at the moment of cargo locking; $S_{З0}$ – tension in haul-lifting cable at the initial moment of locking taking into account the impact of cargo and cargo carriage; $l_0^{/} = l_0 - H_G$ – initial cable lengs at the moment of cargo locking [8]; l_0 – the length of the hauling cable between the carriage and the upper support at the initial moment of time; $C_{ЗВ}{}^{/}$ – conditional reduced longitudinal stiffness of the cable system during cargo locking

Dependence for the calculation of auxiliary variable t_{0C} that takes into account the start of locking can be written as follows:

$$t_{0C} = \frac{1}{\mathrm{v}}\left(\frac{Q\left[L - x_K(t_0)\right]}{C_{ЗВ}} + H_G\right). \tag{5}$$

where $x_K(t_0)$ – the coordinates of the cargo carriage location on the route of transportation at the initial moment of time t_0.

To determine the tension force of the cable at the initial moment of cargo and carriage locking it is necessary to consider its sharp increase as a result of an impact of cargo to carriage. Having assumed that the kinetic energy of moving load is completely transformed into potential energy of haul-lifting cable deformation [9] tension force in the initial locking time can be defined by the formula:

$$S_{З0} = S_2\cdot\left(1 + \frac{\mathrm{v}}{\sqrt{\frac{Q\cdot\left[L - x_K(t_0)\right]}{C_{ЗВ}}\cdot g}}\right), \tag{6}$$

where $S_{З0}$ – the tension force of the cable at the initial moment of cargo and carriage locking; S_2 – the tension force of the haul-lifting cable while lifting the load; g – free fall acceleration.

Conditional reduced longitudinal stiffness of the cable system during cargo locking [1, 8]:

$$C_{ЗВ}{}^{/} = \frac{E_K A_K}{1+\dfrac{\lambda_C E_K A_K}{l_0^{/}}}, \tag{7}$$

where $\lambda_C = \lambda_1 \sin\gamma_1 + \lambda_2 \cos\gamma_1 + \frac{q^2}{12 S_{ПК}^3}\cdot\sum_{i=1}^{n}\frac{a_i^3}{\cos\gamma_i} + \lambda_Л + \sum_{i=1}^{n}\lambda_{\delta i}$ – reduced cable system compliance during locking.

The resulting expression for calculating cable tension force at the time of cargo locking will look like:

$$S(t) = S_3 = S_{30} + \frac{C_{ЗВ}{}^{/}}{l_0^{/}}\left(\text{v}\cdot t - \left(\frac{Q\left[L - x_K(t_0)\right]}{C_{ЗВ}} + H_G\right)\right). \tag{8}$$

When transporting cargo and the cargo carriage by the carrying cable the value of tension force in haul-lifting cable depends on the external components of the movement resistance forces of loaded cargo carriage [7, 8]:

$$S(t) = S_4 = S_f + S_{f2} + S_i(t), \tag{9}$$

where S_4 – tension in haul-lifting cable during the cargo transportation; S_f – the resistance force of cargo carriage movement by carrying cable; S_{f2} – the resistance of timber package tops sliding during semi-suspended transportation; $S_i(t)$ – raising resistance force.

The magnitude of the movement resistance force of cargo carriage depends on: the construction of the cargo carriage, the number and diameter of its running wheels, hardness, deflection and the degree of carrying cable separation, the speed of cargo transporting [7]. The total resistance force of cargo carriage movement can be determined from the expression [7]:

$$S_f = (G+Q)\cdot f_\Sigma, \tag{10}$$

where f_Σ – the total drag coefficient of the cargo carriage transporting (for cables of standard 2688 [7]).

When transporting a timber in a semi-suspended state some part of the trunk slides over the surface of the cutting area and creates additional movement resistance. The sliding resistance force during semi-suspended transportation can be calculated by the formula [5]:

$$S_{f2} = Q\cdot k_P\cdot f_2, \tag{11}$$

where $k_P = 0{,}2...0{,}4$ – coefficient of cargo weight distribution [5,7]; f_2 – slide resistance coefficient ($f_2 = 0{,}4...0{,}8$, [5, 7]).

The rising resistance force component is determined taking into account the weight of the mobile cables. To the drive equipped with hauling cable (Fig. 2a) the component of the resistance force of cargo rising, cargo carriage rising and mobile hauling cable $S_i(t)$ can be defined by the formula [5]:

$$S_i(t) = \pm\left[(G+Q) + l_0^T(t)\cdot q_K\cos\beta\right]\sin\gamma(t), \tag{12}$$

where q_T – linear weight of hauling cable; $l_0^T(t)$ – length of hauling cable between the carriage and the upper support, which is located closer to the drive; $\gamma(t)$ – variable angle of cargo carriage lifting.

For the cable plant drive, equipped with hauling and reverce cables (Fig. 2,b) the expression to determine the raising resistance force component of looks like [5]:

$$S_i(t)=\pm\Big[(G+Q)+\Big(l_0^T(t)\cdot q_K+\big[l_1^{3B}(t)-l_2^{3B}(t)\big]\cdot q_{K2}\Big)\cos\beta\Big]\sin\gamma(t), \quad (13)$$

where q_{K2} – linear weight of reverce cable; $l_{K2}^{/}(t)$ – the length of the part of reverce cable between the carriage and distant support; $l_{K2}(t)$ – the length of reverce cable in whole span; β – the slope angle of the span chord to the horizon; $\gamma(t)$ – lifting angle of cargo carriage.

When calculating the rising resistance force component $S_i(t)$ one should consider the variable angle of cargo carriage lifting that depends on the slope angle of the span chord of carrying cable to the horizon [4]:

$$\gamma(t)=\text{arctg}\left(\text{tg}\,\beta+\frac{2x_K(t)-L}{2H}\left(\frac{q_H}{\cos\beta}+\frac{Q}{L}\right)\right), \quad (14)$$

where H – horizontal component of tension force in carrying cable.

$$H=\frac{L^2}{8f_{\max}}\left(\frac{q_H}{\cos\beta}+\frac{2Q}{L}\right), \quad (15)$$

where $f_{\max}$ – value of the maximum cable sagging.

Value of the cable sagging of timber transporting plants are within: $\frac{f_{\max}}{L}=\left(\frac{1}{20}\ \dots\ \frac{1}{30}\right)$ [1, 2, 5, 7].

If the cable plant is equipped with a reverse cable (Fig. 2.1, b) one should additionally consider the resistance to rotation of the reverse cable drum and to reverse cable movement [5]: $$S_{3B}(t)=j^{/}G_Bf_0\frac{d_C}{d_{B2}}\pm q_{K2}\left(l_{K2}(t)\cdot-l_{K2}^{/}(t)\right)\cos\beta\cdot\sin\gamma(t), \quad (16)$$

where $j^{/}$ – factor for the drum braking ($j^{/}=1,2...1,3$, [5]); G_B – weight of the drum drive with wound reverse cable; f_0 – coefficient of friction in the bearings of the drum; d_C – drum pin diameter; d_{B2} – reverse cable drum diameter.

Cargo can be transported up and down the route of the cable plant. The transportation direction in expressions (12), (13) and (15) consider by positive or negative sign (in the case of lifting - positive).

In real situation the plant drive work begins when the hauling cable is loosen, the load is placed on the ground. Time from the run of the drive engine to the beginning of the cargo movement may be greater than the time of of the engine work stabilization [8]. Analysis of experimental research of such plants as VTU-3 [2] and LL-24 [8] showed that in primary stage nature of the haul-lifting cable tension force change is close to the straight line. Therefore, the definition of cable tension force in primary stage we perform using the dependence: $$S(t)=S_1=\frac{Q}{t_1}\cdot t, \quad (17)$$

where S_1 – tension in haul-lifting cable during cable slack removing; t_1 – the duration of the initial period of cable slack removing (till the beginning of cargo lifting up from the ground).

To determine the value of time t_1 and the duration of the other stages of the working cycle of the cable plant drive we assume that conditional reduced longitudinal deformation of cable system for an initial time period t_1 is equal to the length of haul-lifting cable wound on a drive drum for the same time t_1. Until the cargo is up off the ground it is fixed. At the moment of the cargo lifting beginning the haul-lifting cable tension force is equal to the weight of cargo. Expressing the conditional reduced deformation of cable system as the weight of the cargo and equating it to the length of haul-lifting cable wound during the time t_1, we get:

$$\mathrm{v} \cdot t_1 = \frac{Q}{c_{k3B}} = \frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}}, \tag{18}$$

where c_{k3B} – coefficient of conditional longitudinal stiffness of cable systems.

Considering the expression (18), a condition to determine the time limits of primary stage of cable slack remowing would look like this:

$$0 \le t_1 \le \frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B} \cdot \mathrm{v}}. \tag{19}$$

Time limits of the load lifting stage t_2 are dependent on the speed of winding of the cable on the drive drum and cargo lifting height:

$$\frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B} \cdot \mathrm{v}} < t_2 \le \frac{1}{\mathrm{v}}\left(\frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}} + H_G\right), \tag{20}$$

where t_2 – the duration of the cargo lifting.

The period of the carriage and cargo locking t_3 is accepted on the basis of cable plant observations in working conditions [8]. Locking time depends mainly on the skill of the winch operator and continues 0,3..0,8 s, but sometimes, the time of joining cargo and carriage can reach 2 seconds. Time limits of the locking period:

$$\frac{1}{\mathrm{v}}\left(\frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}} + H_G\right) < t_3 \le \frac{1}{\mathrm{v}}\left(\frac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}} + H_G\right) + t_C, \tag{21}$$

where t_C – the accepted time value of cargo and carriage locking; t_3 – duration of cargo locking period.

Time to move cargo and carriage depends on the total length of the transport route L and the location coordinates $x_K\left(t_0\right)$ of the cargo carriage in the initial moment of time. Duration of the cargo transporting stage can be determined from the condition that the length of the wound during this time haul-lifting cable on the drum should not exceed the length of the free part of haul-lifting cable between the drive and carriage coordinate at the initial moment of time t_0. As cable slack of timber transporting plants are small, the length of the free area with sufficient accuracy can be calculated taking the cable slack path as the parabola [2, 4, 7, 8]. Conditions for determining the duration of the cargo carriage moving t_4 can be written as follows:

$$\begin{cases} t_4 > \dfrac{1}{\mathrm{v}}\left(\dfrac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}} + H_G\right) + t_C, \\[2ex] t_4 \le \dfrac{1}{\mathrm{v}}\left(\dfrac{Q\left[L - x_K\left(t_0\right)\right]}{C_{3B}} + H_G + \dfrac{\left(L - x_K\left(t_0\right)\right)}{\cos\beta} + \dfrac{\left(gq_K\right)^2 \cdot \left(L - x_K\left(t_0\right)\right)^3}{24 \cdot H^2}\cos\beta\right) + t_C. \end{cases} \tag{22}$$

where t_4 – duration of cargo and cargo carriage transportation period.

Considering the (19 - 22), the final dependances to determine the haul-lifting cable tension force can be written in the following form:

$$S(t)=\begin{cases}\dfrac{C_{3B}\cdot \text{v}}{L-x_K(t_0)}\cdot t, коли & 0\le t\le \dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}\cdot \text{v}},\\ S_2, \quad коли & \dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}\cdot \text{v}}<t\le \dfrac{1}{\text{v}}\left(\dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}}+H_G\right),\\ S_3, \quad коли & \dfrac{1}{\text{v}}\left(\dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}}+H_G\right)<t\le \dfrac{1}{\text{v}}\left(\dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}}+H_G\right)+t_C,\\ S_4, \quad коли & \begin{cases} t>\dfrac{1}{\text{v}}\left(\dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}}+H_G\right)+t_C\\ t\le \dfrac{1}{\text{v}}\left(\dfrac{Q\left[L-x_K(t_0)\right]}{C_{3B}}+H_G+\dfrac{L-x_K(t_0)}{\cos\beta}+\dfrac{(gq_K)^2\cdot\left(L-x_K(t_0)\right)^3}{24\cdot H^2}\cos\beta\right)+t_C.\end{cases}\end{cases} \quad (23)$$

where S_2, S_3, S_4 – the haul-lifting cable tension force during cargo lifting, locking cargo and cargo carriage and transportation of cargo carriage by carrying rope.

The research of cable multilayer winding influence. The expression (1) shows that on the value of the process resistance forces moment $M_{CO}(t)$ also affects variable radius of the drive drum with a wound cable. Considering that in cable timbertransporting plants drives is used multilayer cable winding, drum radius with wound cable $r_H(t)$ can be submitted by the length $l_K(t)$ of cable wound on the drum. This length can be submitted by known geometric dimensions of the drum and the diameter and number of wound on the drum cable layers [3, 10]:

$$l_K(t)=\pi\cdot\frac{L_B}{d_K}\cdot n(t)\cdot\left[d_B+C_y\cdot d_K\cdot\left(n(t)-1\right)\right] \quad 24)$$

where $l_K(t)$ – the length of cable wound on the drum; $n(t)$ – the number of wound on the drum cable layers; $d_Б$, $L_Б$ – the diameter and length of the working surface of the drum; d_K – diameter of the cable that is wound; C_y – cable inset density ratio ($C_y=0{,}85...1$).

For one turn of the drive drum wounds one wind of cable. Therefore, a variable number of wound cable layers $n(t)$ we submit by the drive drum rotational speed or its angular velocity:

$$n(t)=n_0+\frac{n_B(t)\cdot d_K\cdot t}{60L_B}=n_0+\frac{\omega_B(t)\cdot d_K\cdot t}{2\pi L_B}, \quad (25)$$

where $n_Б(t),\omega_Б(t)$ – rotational speed and angular velocity of the drive drum with a rope; n_0 – the number of wound cable layers at the initial moment of time.

The required length of haul-lifting cable that is wound on the drive drum, is the sum of the lengths of cable in the plant span considering slack [2, 4, 7] and length of cable stock l_A [3]. As general cable capacity of drive drum and the placement coordinate $x_K(t_0)$ of cargo carriage in span are well-known, the length of wound on a drum cable at the initial moment of time taking into account the cable slack and the cable stock can be obtained from:

$$l_0=l_K(t_0)=l_A+\frac{x_K(t_0)}{\cos\beta}+\frac{q_K^2\cdot x_K(t_0)^3}{24H^2}\cos\beta, \quad (26)$$

where l_A – extra cable reserve.

Substituting (26) into (24) and making arithmetic transformation, we obtain an expression for determining the number of wound cable layers at the initial moment of time t_0:

$$n_0 = \frac{C_y d_K - d_B + \sqrt{\left(d_B - C_y d_K\right)^2 + \dfrac{4C_y d_K{}^2 l_0}{\pi \cdot L_B}}}{2C_y d_K}. \qquad (27)$$

An expression to determine the variable radius of the drive drum with a wound cable at the arbitrary moment of time can be written in the following form [10]:

$$r_H\left(t\right) = \frac{d_B}{2} + d_K \cdot \left(n^{/}\left(t\right) - 0{,}5\right), \qquad (28)$$

where $n^{/}\left(t\right)$ – the number of wound cable layers, calculated by formula (25) and approximated to the bigger integer values, that is $n^{/}\left(t\right) = round\left[n\left(t\right)\right]$.

Results. Numerical calculation example based on proposed dependences and using input data from Table 1 are shown in Fig.3, Fig.4. For this calculations Mathcad 15.0 system application was developed.

Table 1 Input data for calculation of process loads acting on the cable timber-transporting plants drive

Parameter	Designation	Dimension	Value
Rotational speed of the drive drum	n_B	rpm	49
Diameter of the drum with haul-lifting cable	d_B	m	0,3
Diameter of the drum with reverse cable	d_{B2}	m	0,25
Mass of the haul-lifting cable drum	$m_Б$	kg	30
Mass of the reverse cable drum	$m_{Б2}$	kg	35
Length of the working surface of the haul-lifting cable drum	$L_Б$	m	0,6
Length of the working surface of the reverse cable drum	$L_{Б2}$	m	1
Diameter of the hauling (haul-lifting) cable	d_K	m	0,0097
Diameter of the reverse cable	d_{K2}	m	0,0081
Linear weight of haul-lifting cable	q_K	kg / m	0,3835
Linear weight of reverce cable	q_{K2}	kg / m	0,2535
Length of the span	L	m	400
Cargo weight	Q	kN	16
placement coordinate of cargo carriage at the initial moment of time	$x_K\left(t_0\right)$	m	80
Length of spare hauling cable	l_A	m	20
Length of spare reverce cable	$l_Б$	m	35
Cable inset density ratio	C_y	-	0,95
Height of cargo lifting	H_G	m	4
Slope angle of the span chord to the horizon	β	deg	30
Time of cargo and carriage locking	t_C	s	0,5

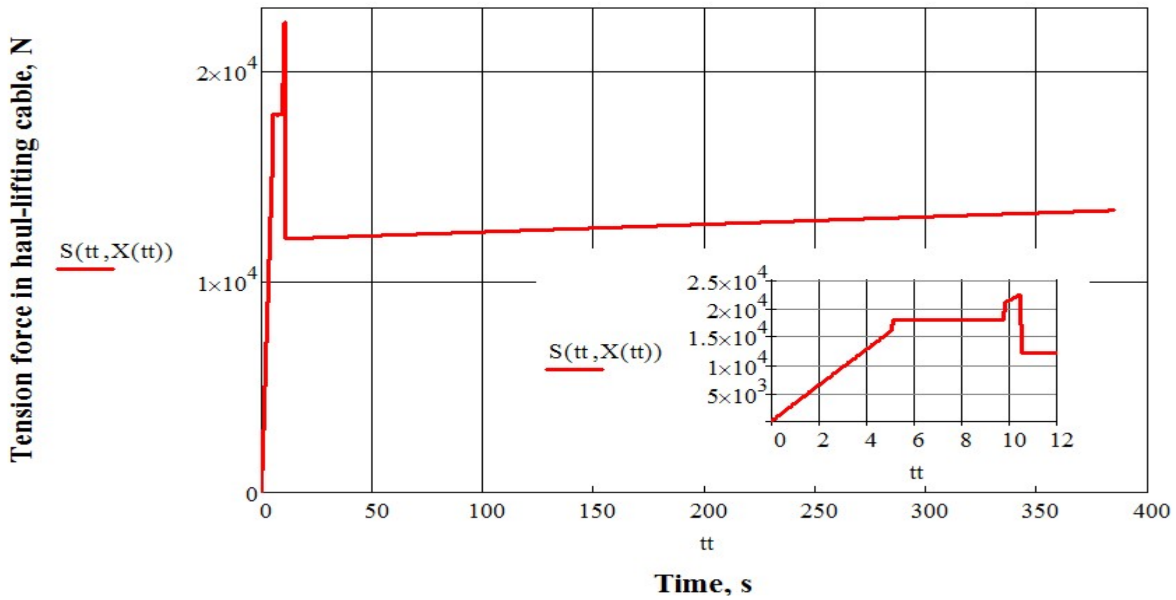


Fig. 3. The time dependence of tension force in haul-lifting cable

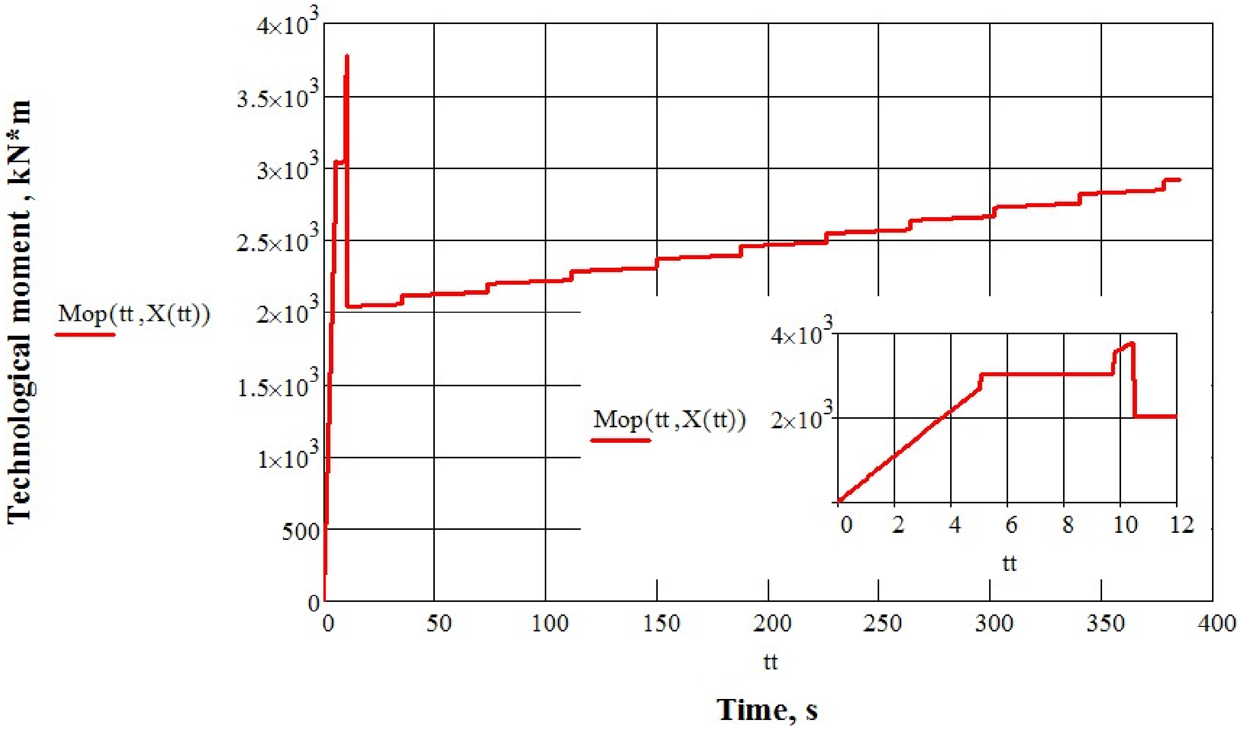


Fig. 4. The time dependence of the technological moment acting on drive drum with haul-lifting cable

Conclusions. The time dependence of tension force in haul-lifting cable (Fig. 3) shows that the maximum short-term efforts (23 кN) in haul-lifting cable occurs at the time of locking of cargo and carriage at the fifth second of drive work.

Analysis of time dependence of the technological moment on the drive drum (Fig. 4) showed that with increasing number of winding cable layers the moment of resistance forces will increase and can grow closer in size to the moment of 3,8 *kNm* that operates in the case of cargo lifting.

Therefore, research work requires not only drive work during a short transitional regimes, but also the whole technological cycle of cable plant work. Particular attention should be paid to the size and nature of dynamic loads in the drive at the time of wound cable transition to a new layer.

Obtained dependences, together with appropriate software era needed for mathematical modelling of dynamic oscillation processes in drives and justification of choice of their basic design parameters and safe modes of operation.

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Особливості розрахунку змінних технологічних навантажень, що діють на приводи підвісних канатних лісотранспортних установок

Удосконалено теоретичні методи розрахунку технологічних зусиль у приводах канатних лісотранспортних установок із врахуванням тривалості етапів технологічного циклу роботи установки, багатошарового намотування канатів на приводні барабани, зусилля натягу, що змінюється і залежить від режиму роботи канатної установки та експлуатаційних параметрів.

Ключові слова: привод канатної лісотранспортної установки, технологічні навантаження, тягово-вантажопідіймальний канат, сила натягу канату.

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MODELING PROPERTIES OF BLOCKBOARDS MADE OF POST-CONSUMER WOOD ON THE BASIS OF THE FINITE ELEMENT METHOD

An approach has been proposed to predict properties of blockboards made of Post-consumer wood by using the finite element method. A model of physical and mechanical properties of PCW strips has been proposed using finite-element analysis of blockboards based on cylindrical coordinate system of the anisotropy of constant elasticity. Substantiation of new design of PCW-made blockboard which is based on the use of the system of finite element analysis allows to identify the shortcomings of these products at the conceptual stage of the project and correct them before fabrication according to

the given engineering specifications. The proposed optimal pattern of layout of annual layers in adjacent strips of PCW-made blockboards, which provides improved shape stability (reduced warpage) of the design while reducing stress arising from the increasing moisture content of the product in the process of operation. Mathematical models that predict (describe) the strength and shape stability of PCW-made blockboards have been proposed. The developed model can be applied to study and optimize new designs of blockboard in terms of strength and deformability.
Keywords: wood, post-consumer wood (PCW), blockboard (BB), shape stability, strength, mathematical models, modeling properties, predicting properties, finite element method (FEM).

Problem formulation. The use of post-consumer wood (PCW) under current conditions for the material recycling is particularly relevant today [12-31]. As the resources of primary wood in Ukraine are limited, the integrated use of secondary resources solves two problems: the problem of virgin raw materials and the problem of waste wood, which is wood after consumption – used wood [15-21]. Thus, it becomes urgent to substitute the primary wood for PCW with appropriate characteristics, in particular in the manufacture of particleboard (PB) [16, 17, 19, 20, 27, 28] and of blockboards (BB) [15, 22, 25, 30].

To ensure the quality of PCW-made blockboards in the form of new structures, it is necessary to consider the physical and mechanical properties of PCW blanks and their stress-strain state [4-7, 10, 31]. Strength, reliability, shape stability and durability of PCW-made blockboards is strongly dependent on the correct dimensioning of strips, laying of strips in cores, types of facing [8, 9, 24].

Today, a great variety of methods are widely used to assess the strength of products. Due to the development of information technologies in the research field, modeling of manufacturing processes has gained wide-spread acceptance. It has become possible to predict the stress-strain state of structures by using, above all, the finite element method (FEM) [7, 8, 10]. All this enables the development and implementation of new and effective methods of calculation and optimization of study objects, in particular PCW-made blockboards. The study on the strength and shape stability of PCW-made blockboards, based on the modeling of their deformation during shrinkage and swelling with consideration for anisotropy of wood, is of great practical interest and belongs to the priority direction of research activities at the UNFU [10-31].

The purpose of the study is prediction of the properties (strength and shape stability) of PCW-made blockboards by using the developed mathematical models.

The goal of the study is to increase the efficiency and quality of new PCW-made constructions of blockboard by structural analysis based on the numerical methods of calculation of stress-strain state and by reducing costs in the preparation of PCW to use.

The practical importance of the study – improving the shape stability of PCW-made blockboards based on the modeling of their deformation during drying and swelling, taking into account the anisotropy of the wooden strips.

Hypothesis of the study – modeling of manufacturing processes during recycling of PCW into a high quality blockboard.

Innovation of the study – description of the stress-strain state of PCW-made BB using the method of linear elements, which enables the development and introduction of new and efficient methods of calculation and optimization of design objects.

The objectives of the study:

- to propose new designs of PCW-made blockboards and their analysis;

• to develop an optimal pattern of arrangement of annual rings in adjacent strips in PCW-made blockboards for reducing the waviness of the design while reducing the stresses that can occur during wetting of the wood in the process of operation.

• to develop mathematical models for predicting the properties of PCW-made blockboards;

• to develop a practical method of calculating the blockboard, which will take into account the peculiarities of physical and mechanical properties of PCW.

• to propose, on the basis of the finite element method and the integral CAD/CAE-systems, a model describing the properties of strips of PCW as the components of the blockboard.

PCW-made blockboard design. Variously designed blockboards were used to conduct a detailed study of the effects of PCW physical and mechanical properties on BB shape stability. The PCW-made BB constructions involved the use of softwood strips or strips cut out from wood particle board sandwiched between plywood or wood fiberboard. Blockboards were also made of primary wood to compare the results obtained. All the blockboards were fabricated 22 mm in thickness in accordance with the DIN 68705-2:2014-10 [11] and GOST 13715:1978 [2].

The width of the strips amounted to 20, 40, 60 mm, while their thickness after double-surface planing was 14 mm. Accordingly, the thickness of face decks that are glued on either side of the blockboard was 44 mm each. The sizes in the blockboards used for shape stability studies made up 450×450×22 mm. PCW-made blockboards of various constructions are presented in Fig. 1, Fig. 2 and Fig. 3.

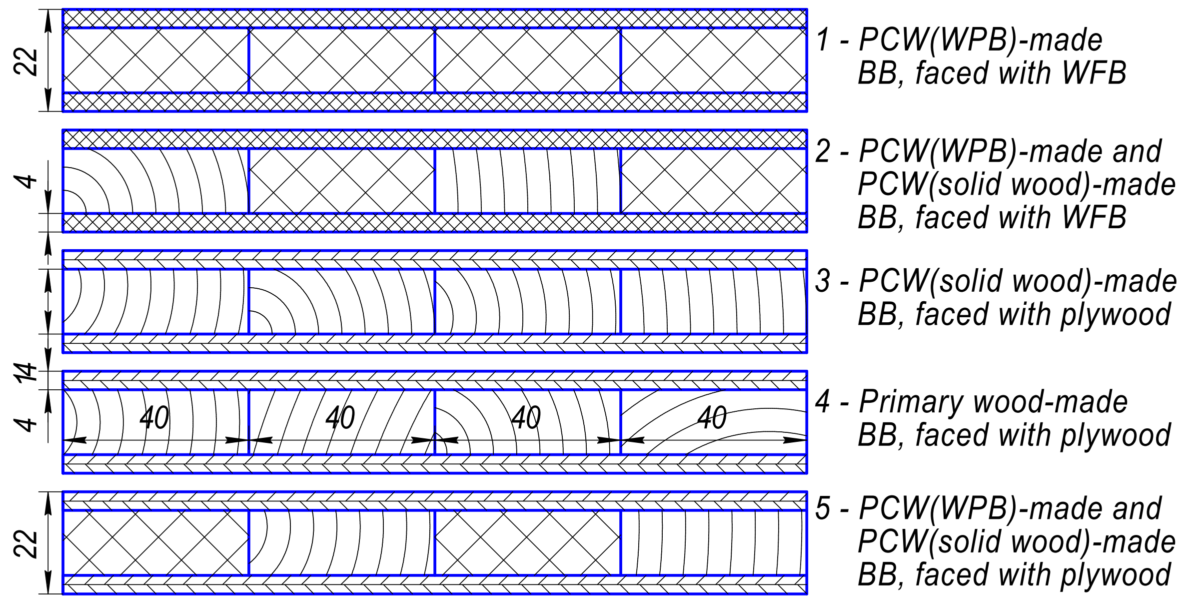

Fig. 1. Combined PCW-made blockboards with strips 40 mm wide.

To ensure shape stability of PCW-made blockboards which operate under conditions of varying humidity, it is desirable to apply the 1:3 aspect ratio in the cross-section of strips, while annual rings angle in the ends of the strips shall not be less than 60º. A mathematical dependence has been first proposed which adequately describes the prediction between shape stability of combined blockboards and the width of various PCW-made strips. To ensure shape stability of PCW-made blockboards which operate under conditions of varying humidity, it is desirable to apply the 1:3 aspect ratio in the cross-section of strips, while annual rings angle in the ends of the strips shall not be less than 60º (Fig. 4).

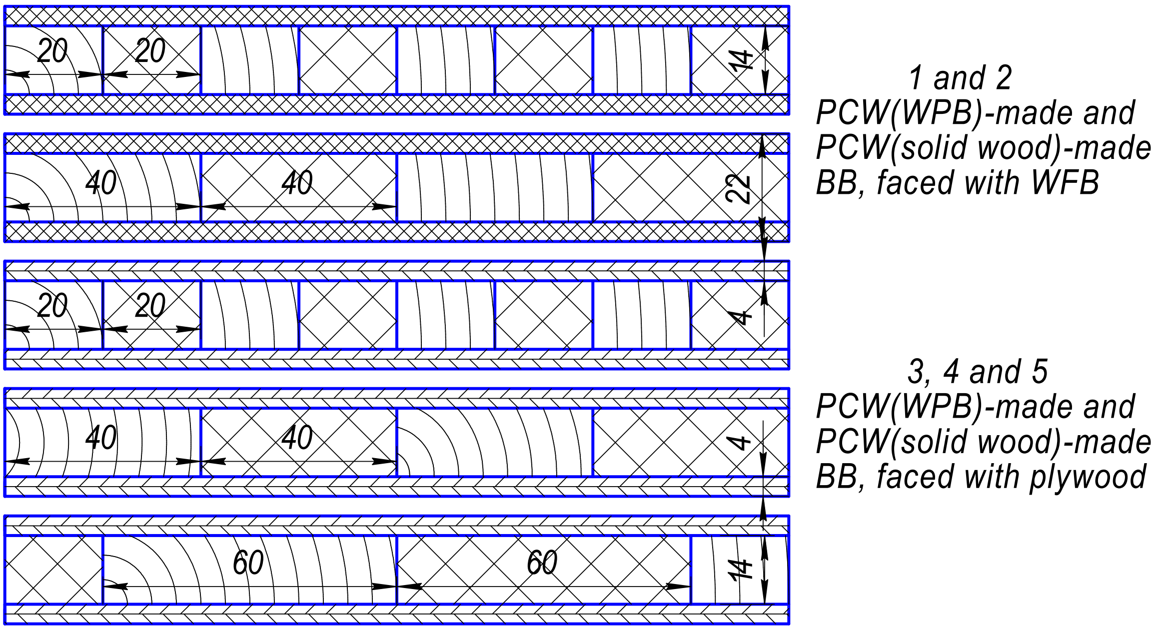

Fig. 2. Combined PCW-made blockboards with strips 20, 40, 60 mm wide.

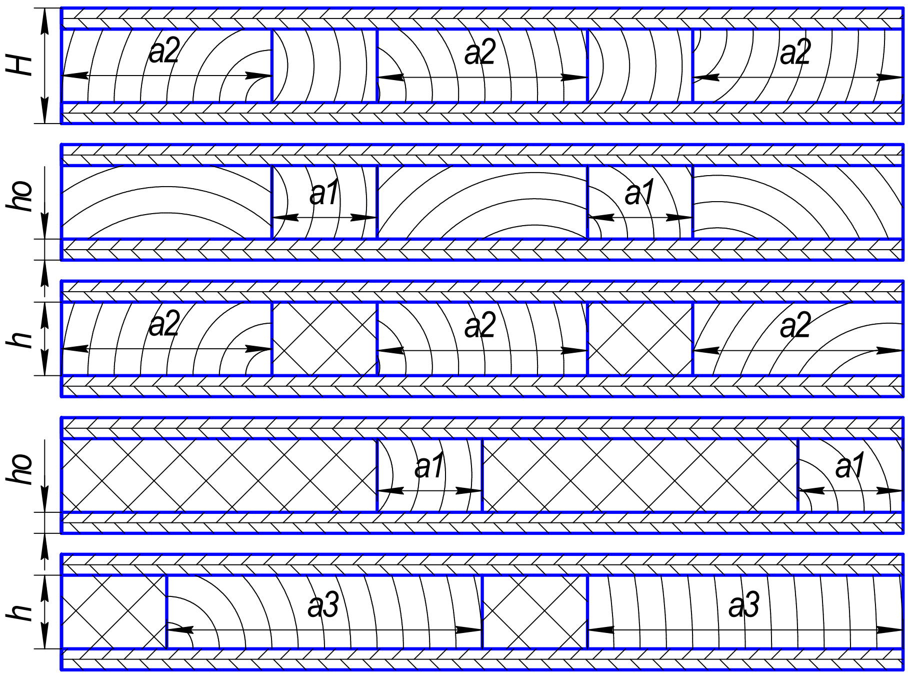

Fig. 3. Combined PCW-made blockboards with different width strips
(PCW(WPB)-made and PCW(solid wood)-made BB, faced with plywood)

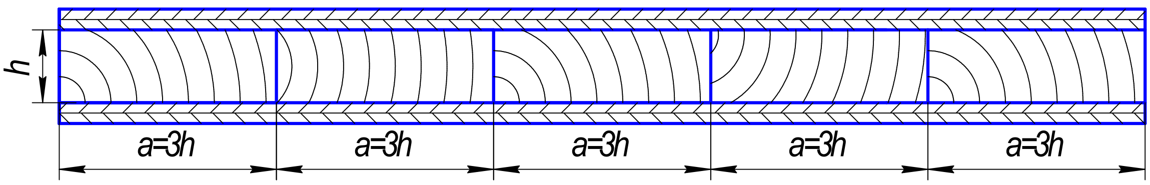

Fig. 4. PCW-made blockboards with equally width strips
(to apply the 1:3 aspect ratio in the cross-section of strips,
while annual rings angle in the ends of the strips shall not be less than 60^{o})

The modeling technique. The methods of predicting the properties of block-boards, which consist of glued strips (rods) made of PCW, is based on modeling the stress-strain state of the product which occurs during the wood swelling when the humidity increases. The computer systems of the finite-element analysis allow for taking into account the anisotropy of physical and mechanical properties of PCW, as well as its characteristics during changes in humidity.

A great contribution to the study of the anisotropy of elastic and strength properties of wood was made by E.K. Ashkenazi [1]. For wood products, depending on the shape, size and orientation in cross-section, it is possible to use the following types of calculation patterns of anisotropy: orthogonal, cylindrical, rectangular or transversal. Since wood is considered to be a body with a strongly pronounced cylindrical anisotropy of physical and mechanical properties, the structural characteristics of wood are noted for explicitly marked differences in elastic properties in different directions. The application of these patterns of cylindrical anisotropy for solving problems of mechanics of deformed solids to calculate the PCW-made blockboard is important from a practical point of view when it is impossible to neglect the curvature of annual rings, that is, in the examination for shape stability of PCW-made blockboards and strips of PCW during the swelling and shrinkage.

Using Hooke's law, elastic anisotropy of wood can be described using the theory of elasticity for anisotropic body. Wood has a linear relationship between strain ε and stress σ, in particular for short-term loads.

In the blockboard which contains PW strips with pronounced anisotropy, the flexibility matrix [B], connecting the six components of the stress with components of the strain, contains no more than 21 independent variable.

Normally, the PCW strips which are in the blockboard core can have an initial strain due to temperature or humidity. Let $\{\varepsilon_o\}$ denote this strain , then the stress will be determined by the difference between the current and initial deformations.

In addition, the PCW strips which are in the blockboard core can have initial stresses $\{\sigma_o\}$. Thus, under the assumption of elastic behavior of PCW strips, the ratio between stresses and strains will be linear:

$$\{\sigma\} = [B](\{\varepsilon\} - \{\varepsilon_o\}) + \{\sigma_o\}, \text{ or } \{\varepsilon\} = [B](\{\sigma\} - \{\sigma_o\}) + \{\varepsilon_o\}. \tag{1}$$

where: [B] is the matrix of flexibility (elasticity), which contains characteristics of PCW strips; $\{\varepsilon\}$ is the strain of the strips; σ is the stress of the strips; σ_0, ε_0 are the initial stress or deformation of PCW strips that are associated with moisture content.

The general view of the matrix [B] with the use of usual elastic constants – the elastic modulus $\boldsymbol{E}$ and Poisson's ratio $\boldsymbol{\nu}$ – takes the form:

$$[B] = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)} \times \begin{bmatrix} 1 & \frac{\nu}{1-\nu} & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-\nu} & 1 & \frac{\nu}{1-\nu} & 0 & 0 & 0 \\ \frac{\nu}{1-\nu} & \frac{\nu}{1-\nu} & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2(1-\nu)} \end{bmatrix} \tag{2}$$

Flexibility matrix for wood which has three planes of elastic symmetry, size 6 x 6, takes the form:

$$[B]=\begin{bmatrix} \frac{1}{E_r} & \frac{-\mu_{tr}}{E_r} & \frac{-\mu_{ar}}{E_r} & 0 & 0 & 0 \\ \frac{-\mu_{rt}}{E_t} & \frac{1}{E_t} & \frac{-\mu_{at}}{E_t} & 0 & 0 & 0 \\ \frac{-\mu_{ra}}{E_a} & \frac{-\mu_{ta}}{E_a} & \frac{1}{E_a} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{rt}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{ta}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{ra}} \end{bmatrix} \tag{3}$$

where: ***E*** is the elasticity modulus of PCW; ***μ*** is the coefficient of transverse deformation (GOST 16483.29-73) [3]; ***G*** is the shear modulus (GOST 16483.30-73) [4].

To denote the transverse strain μ with different directions of compression relative to the annual rings and fibers, ***μ*** will have two indexes: the first one indicates the direction of transverse strain, and the second one shows the direction of compression that is causing the transverse strain. The direction along the grain is denoted by the index *a,* the direction across the grain in radial direction – by the index ***r***, and in the tangential direction - by the index ***t***.

For the coefficients of transverse strain ***μ***, the following notations are used:

- μ_{ra} ; μ_{ta} are the coefficients of the transverse strain in the radial and tangential directions during compression along the grain;
- μ_{ar} ; μ_{tr} are the coefficients of transverse strain along the grain and in the tangential direction when compressed in the radial direction;
- μ_{at} ; μ_{rt} are the coefficients of the transverse strain along the grain and in the radial direction when compressed in tangential direction.

For the shear moduli **G**, the following designations are used:

- G_{ra} is the shear modulus in the radial plane of the section under compression at an angle of 45° to this plane and the direction of the grain;
- G_{ta} is the shear modulus in the tangential plane of the section under compression at an angle of 45° to this plane and the direction of the grain;
- G_{rt} is the shear modulus in the radial or tangental plane under compression at an angle of 45° to these planes.

For orthotropic strips of blockboards (with the small cross section or volume of wood), of 12 elastic constants, which are included in the flexibility matrix [B], only 9 are independent because the following conditions are always true:

$$\frac{\mu_{ra}}{E_a}=\frac{\mu_{ar}}{E_r}; \qquad \frac{\mu_{ta}}{E_a}=\frac{\mu_{at}}{E_t}; \qquad \frac{\mu_{rt}}{E_t}=\frac{\mu_{tr}}{E_r}. \tag{4}$$

For transversely isotropic strips of blockboards (with the large cross-section or volume of wood), of 12 elastic constants, which are included in the flexibility matrix [B], only 5 are independent because always true are the following four conditions:

$$-\frac{\mu_{ra}}{E_a}=-\frac{\mu_{ar}}{E_r}=-\frac{\mu_{ta}}{E_a}=-\frac{\mu_{at}}{E_t}; \qquad \frac{1}{E_t}=\frac{1}{E_r}; \qquad \frac{1}{G_{ta}}=\frac{1}{G_{ar}}; \qquad G_{rt}=\frac{E_r}{2(1+\mu_{rt})}. \tag{5}$$

The presented patterns of the orthogonal and transversal anisotropy of mechanical properties of PCW strips can be implemented in CAD/CAE-systems. During the calculation of properties of blockboards, you must select a three-dimensional orthotropic element (strip) and specify its mechanical properties in three directions.

The initial strain ε_0 or the stress σ_0 for PCW strips, that are associated with humidity, in matrix representation can be written in the form:

$$\{\varepsilon_o\} = (W\text{-}W_o)\,[k_r ; k_t ; k_a ; 0 ; 0 ; 0]\,,$$
$$\text{or } \{\sigma_o\} = (W\text{-}W_o)\,[k_r ; k_t ; k_a ; 0 ; 0 ; 0] \tag{6}$$

where : W, W_0 are final and initial moisture of PCW strips ; k_r ; k_t ; k_a are the coefficients of shrinkage (swelling) in the radial, tangential and longitudinal direction, respectively.

It is found that for structures with PCW-made blockboard, it is possible to use orthogonal, rectangular or transversal patters of anisotropy depending on the size of the blockboard and the orientation of the fibers in the strips. A model of physical and mechanical properties of PCW strips has been proposed using finite-element analysis of blockboards based on cylindrical coordinate system of the anisotropy of constant elasticity. It is established that the practical use of cylindrical anisotropy pattern to solve problems in mechanics of deformed solids to calculate the PCW-made blockboard is advisable when it is impossible to neglect the curvature of annual rings, that is, in the analysis of shape stability of blockboards and strips made of PCW when swelling and shrinkage occur.

Mathematical models for predicting properties. Provision of a rationale for the prediction of properties of PCW-made blockboards is based on the following reasoning:

- Physical and mechanical properties of PCW-made blockboards depend on the PCW characteristics, in particular, moisture and cross-breaking strength of the strips.
- Physical and mechanical properties of PCW-made blockboards depend on the type of strips, in particular, strips of solid wood (monolithic or jointed) and strips made of chipboard.
- There is a close correlation between the width of the strips and the species and the cross-breaking strength of the blockboard strips.
- The cross-breaking strength of the strips depends on the pattern of stacking of strips in the blockboard’s core.The shear strength on the glueline region depends on the type of facing material. The cross-breaking strength of the strips depends on the type of facing material and the glue spread for jointing the strips together.
- There is a close correlation between the width and the types of the strips and the shape stability. The shape stability depends on the grain angle in the strips.Bonding of strips in the blockboard increases strength but decreases shape stability;
- The facing layer on each side of the blockboard should be more than 3 mm thick.
- The greater the width of the strips made of particleboard (PB) in comparison with the width of the strips of solid wood, the higher the shape stability, but less strength.

To predict the properties of PCW-made blockboards, it is necessary that all components that affect the indicators of the quality of the obtained blockboards should be taken into consideration (Table 1).

Table 1. Indicators and parameters of PCW-made blockboard

Parameter	Designation	Units of measurement
Width of strips	a	mm
Thickness of strips	h	mm
Width/thickness ratio K_{size} (K_s)	a/h	–
Grain angle in strips	α	degrees
Coefficient of grain angle K_α	90/α	
Cross-bending strength, PCW (solid)	$\sigma_{PCW(solid)}$	MPa
Cross-bending strength, PCW (particleboard)	$\sigma_{PCW(pb)}$	MPa
Ultimate cross-breaking strength, species	$\sigma_{species}$	MPa
Ultimate cross-breaking strength, particleboard	σ_{PB}	MPa
Coefficient for PCW species	$k_{species}$	–
Coefficient for the type of particleboard	K_{PB}	–
Moisture content in PCW (solid)	W_{PCW}	%
Moisture content in PCW (particleboard)	W_{PB}	%
PCW age	N	years
Facing material: plywood, WFB	M_F	–
PCW-made blockboard design	BB_{comm}; BB_{comb}	

Dependence functions of PCW-made blockboard properties on input components:

a) cross-breaking strength of strips: for common PCW-made blockboards

$$\sigma_{comm} = f\,(\sigma_{PCW(solid)};\ K_s;\ K_\alpha;\ k_{species};\ W_{PCW};\ N;\ M_F); \tag{7}$$

- for combined PCW-made blockboards

$$\sigma_{comb} = f\,(\sigma_{PCW(solid)};\ \sigma_{PCW(PB)}\ ,\ K_s;\ K_\alpha;\ k_{species};\ k_{PB};\ W_{PCW};\ W_{PB};\ N;\ M_F); \tag{8}$$

b) shape stability: for common PCW-made blockboards

$$S_{comm} = f\,(\sigma_{PCW(solid)};\ K_s;\ K_\alpha;\ k_{species};\ W_{PCW};\ M_F); \tag{9}$$

- for combined PCW-made blockboards

$$S_{comb} = f\,(\sigma_{PCW(solid)};\ \sigma_{PCW(PB)};\ K_s;\ K_\alpha;\ k_{species};\ k_{PB};\ W_{PCW};\ W_{PB};\ M_F). \tag{10}$$

Taking into account the results of theoretical studies and results of long-term experimental studies and the nature of their trends, the mathematical logarithmic dependences (approximated functions of the research results) have been proposed to predict the characteristics of PCW-made blockboards. Mathematical dependences have the form:

a) to predict the strength of PCW-made blockboards (σ_{BB})

$$\sigma_{\mathrm{BB}} = A \cdot K_\alpha + B \cdot \log_{K_s}(C \cdot \sigma_{PCW}^{(i)}) \tag{11}$$

where: A, B, C are approximation coefficients, which depend on the blockboard design, the properties of PCW strips,type of facing and moisture content; K_α is the coefficient which takes into account the grain angle : $K_\alpha = 90/\alpha$; K_s is the ratio of the width to the thickness of the strips : $K_s = a/h$; $\sigma_{PCW}^{(i)}$ is and the strength of PCW strips.

b) to predict the shape stability of PCW-made blockboard (S_{BB})

$$S_{\mathrm{BB}} = A \cdot K_\alpha + B \cdot \log_{K_s}(C \cdot S_{PCW}^{(i)}) \tag{12}$$

where: A, B, C are approximation coefficients which depend on the blockboard design, the properties of PCW strips, the stress-strain state of PCW strips, type of facing and moisture content; K_α is the coefficient which takes into account the grain angle: $K_\alpha = 90/\alpha$; K_s is the ratio of width to thickness of strips : $K_s = a/h$; $S_{PCW}^{(i)}$ is and the shape stability of the PCW strips. Mathematical models that predict (describe) the strength and shape stability of PCW-made blockboards have been proposed. The developed model can be applied to study and optimize new designs of blockboard in terms of strength and deformability.

Conclusions. An approach has been proposed to predict properties of blockboards made of Post-consumer wood by using the finite element method. It is found that for structures with PCW-made blockboard, it is possible to use orthogonal, rectangular or transversal patters of anisotropy depending on the size of the blockboard and the orientation of the fibers in the strips.A model of physical and mechanical properties of PCW strips has been proposed using finite-element analysis of blockboards based on cylindrical coordinate system of the anisotropy of constant elasticity.It is established that the practical use of cylindrical anisotropy pattern to solve problems in mechanics of deformed solids to calculate the PCW-made blockboard is advisable when it is impossible to neglect the curvature of annual rings, that is, in the analysis of shape stability of blockboards and strips made of PCW when swelling and shrinkage occur.The applied methods of calculation of PCW-made blockboards have been developed that take into account the peculiarities of anisotropy of physical and mechanical characteristics of strips subject to shrinkage and swelling with changing temperature and humidity conditions of the environment.Substantiation of new design of PCW-made blockboard which is based on the use of the system of finite element analysis allows to identify the shortcomings of these products at the conceptual stage of the project and correct them before fabrication according to the given engineering specifications. The proposed optimal pattern of layout of annual layers in adjacent strips of PCW-made blockboards, which provides improved shape stability (reduced warpage) of the design while reducing stress arising from the increasing moisture content of the product in the process of operation. Mathematical models that predict (describe) the strength and shape stability of PCW-made blockboards have been proposed.The developed model can be applied to study and optimize new designs of blockboard in terms of strength and deformability.To ensure shape stability of PCW-made blockboards which operate under conditions of varying humidity, it is desirable to apply the 1:3 aspect ratio in the cross-section of strips, while annual rings angle in the ends of the strips shall not be less than 60^{o}.A mathematical dependence has been first proposed which adequately describes the prediction between shape stability of combined blockboards and the width of various PCW-made strips.

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УДК 674 *Доц. С.В. Гайда, канд. техн. наук – НЛТУ України*

Моделювання властивостей столярних плит із вживаної деревини на основі методу кінцевих елементів

Запропоновано підхід прогнозування властивостей столярних плит із вживаної деревини на основі методу кінцевих елементів. З'ясовано, що в конструкціях СП із ВЖД можна приписувати ортогональну, циліндричну або трансверсальну розрахункову схему анізотропії в залежності від розмірів СП та орієнтації волокон в рейках. Запропоновано модель фізико-механічних властивостей рейок із ВЖД при кінцево-елементному аналізі СП на основі циліндричної системи координат анізотропії постійних пружності. Встановлено, що практичне використання схеми циліндричної анізотропії під час вирішення задач механіки твердого деформованого тіла для розрахунку СП із ВЖД доцільно, коли не можливо знехтувати кривизною річних шарів, тобто при аналізі формостійкості СП та рейок з ВЖД при розбуханні і усушці. Розроблено прикладна методика розрахунку СП із ВЖД, що дозволяє врахувати особливості анізотропії фізико-механічних характеристик рейок з урахуванням усушки і розбухання їх при зміні температурно-вологісних умов довкілля. Обґрунтування нових конструкцій СП із ВЖД, яке базується на використанні систем кінцево-елементного аналізу, дозволяє виявити недоліки даних виробів на концептуальній стадії проекту і виправити їх до початку виготовлення з урахуванням заданих технічних умов. Запропоновано оптимальну схему компонування річних шарів в суміжних рейках СП із ВЖД, яка забезпечує покращення формостійкості (зниження жолобленості) конструкції при одночасному зменшенні напружень, що виникають при збільшенні вологості виробу в процесі експлуатації. Запропоновано математичні моделі, які прогнозують (описують) міцність та формостійкість СП із ВЖД. Розроблена модель може бути застосована для дослідження і оптимізації СП нових конструкцій за умовами міцності і деформативності. Для забезпечення формостійкості СП із ВЖД, які експлуатуються в умовах змінної вологості, бажано застосовувати співвідношення сторін у поперечному перерізі рейок 1:3, а кут нахилу річних шарів в торці рейок повинен бути не менше 60°. Вперше запропоновано математичну залежність, що адекватно описує формостійкість комбінованих СП від ширини різних рейок із ВЖД.

Ключові слова: деревина, вживана деревина, столярна плита, формостійкість, міцність, математичні моделі, моделювання властивостей, прогнозування властивостей, метод кінцевих елементів (МКЕ).

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UNDERSTANDING WOOD MODIFICATION THROUGH AN INTEGRATED SCIENTIFIC AND ENVIRONMENTAL IMPACT APPROACH (IN THE FRAMEWORK OF COST ACTION FP1407)

About. The COST Action FP1407 “Understanding wood modification through an integrated scientific and environmental impact approach” started in March 2015 and will last until April 2019. The main aim of the Action is to characterize the relationship between modification processing, product properties, and the associated environmental impacts. This includes the development and optimization of modified processing and quantification of the impacts of emerging treatment technologies compared to traditional processing and alternative materials to maximize sustainability and minimize environmental impacts. The Action provides the critical mass of Europe-wide knowledge needed to achieve the future developments in the wood modification processing with integrating assessment of process parameters, developed product properties, and environmental impacts.

Members. The Action has members from 96 institutions (R&D and industry) coming from 24 European countries, 3 COST Near Neighbor Countries (Ukraine, Albania, and Tunisia) and 5 COST international partner countries (USA, Canada, New Zealand, South Africa, and Chile).

Key areas of the Action FP1407. *Wood Modification & Product Category Rules*: Development of product category rules for modified wood based on the scientific and industrial state-of-the-art of commercialized and developing modified wood products and technologies. For details contact Dick Sandberg (SE):dick.sandberg@ltu.se

Environmental Impact Assessment & Life Cycle Assessments: Objective environmental impact assessments of commercial modification processes and incorporation of environmental impact assessments into wood modification processing and product development, including recycling and upgrading at the end of service life. For details contact ChristelleGanne-Chedeville (CH): christelle.ganne-chedeville@bfh.ch. *Environmental Products Declarations*: Development of environmental product declarations of modified wood and harmonization of various national EPDs in the field of wood modification. For details contact Callum Hill (UK): enquiries@jchindustrial.co.uk

*Communication & Knowledge Transfer:*Dissemination, evaluation, and exploitation of the Action's results together with establishing a strong network with the relevant industrial stakeholders. For details contact Edo Kegel (NZ): edo@edokegel.nl

Networking Tools of the Action FP1407. Scientific conferences, scientific and professional workshops, training schools, short term scientific missions.

To learn more about the Action FP1407. Visit web page: http://costfp1407.iam.upr.si/en/; Follow us on Twitter, LinkedIn and like us on Face-book. Get in touch: fp1407@iam.upr.sior roman.shchupakivskyy@nltu.edu.ua

Sidebar: Cooperation in Science and Technology, COST.

COST is the longest-running European framework supporting transnational cooperation among researchers, engineers and scholars across Europe. Based on a European intergovernmental framework for cooperation in science and technology, COST has been contributing since its creation in 1971 to closing the gap between science, policy makers and society throughout Europe and beyond. COST funds pan-European, bottom-up networks of scientists and researchers across all science and technology fields. These networks, called *COST Actions*, promote international coordination of nationally-funded research.

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Термічне модифікування деревини: основні засади в контексті інтегральних науково-екологічних аспектів (в рамках проекту COST Action FP1407)

Основна мета проекту – встановлення закономірностей між процессами термічного модифікування деревини, властивостями отриманих продуктів, а також пов'язаних з ними впливів на навколишнє середовище. Проект передбачає оптимізацію існуючих процесів модифікування, оцінку кількісного впливу нових технологій термічного оброблення в порівнянні з традиційною обробкою і альтернативних матеріалів з метою максимального збільшення стійкості і зведення до мінімуму впливу на навколишнє середовище.

Ключові слова: термічне модифікування деревини, принципи каскадного користування, оцінка життєвого циклу, властивості матеріалів, екологічний вплив.

UDC 630*174.754 ***Doctoral candidate M.M. Lisovyy, PhD in Agr. Sciences***

VEGETATIVE PROPAGATION OF *TAXUS BACCATA* L. CULTIVARS 'FASTIGIATA' AND 'AUREA'

Abstract. Analyzed were a number of literature sources related to the research theme. Presented are the results of experimental studies on propagation by cuttings and microcloning of two cultivars of *Taxus baccata* L.: (1) 'Fastigiata' and (2) 'Aurea'. The main aspects of *in vitro* propagation of the plants under study have been described: decontamination of the explants, the composition of nutrient media for initiation, multiplication and rooting; the substrate for adaptation of regenerated plants to soil conditions. The results obtained have been generalized and analyzed.

Key words: *Taxus baccata L.,* 'Fastigiata', 'Aurea', propagation by cuttings, microcloning, explant, sterilization, initiation, multiplication, nutrient medium.

Introduction. Common yew *(Taxus baccata L.)* is a relict species of the Mesozoic era which is listed in the Red book of Ukraine having a nature-conservation status of "vulnerable" [7]. However, the study species is sufficiently resistant under conditions of the urbanized environment and has many ornamental cultivars (forms), which makes it a valuable species for greening of human settlements [3]. The objective of this study was to improve the technology of vegetative propagation of the study cultivars of yew by vegetative means (cuttings and microcloning), since this ensures the reproduction of plants genetically identical to the parent organism.

At present, there are a number of scientific works that are concerned with vegetative propagation of *Taxus baccata* L.: Filonova, G.L. (1999); Usoltseva, A.G. (2009); Z. Abbasin (2010) etc. [2, 4-6,]. However, the above mentioned works deal with breeding standard forms of yew only, and not its ornamental cultivars.

Materials and methods. In our studies, cultivars of yew such as 'Fastigiata' and 'Aurea,' which are most often used in landscaping, were used as the parent tree.

The propagation by cuttings was carried out in two periods: in spring (March) and in summer (June) according to the conventional methods [3]. To accelerate rooting, the following plant growth regulators of different concentrations were used: naphthylacetic acid (NAA) and the *Kornevin* product.

The studies on microclonal reproduction were conducted in the laboratory of plant tissue culture at the Department of forest cultures and forest breeding, UNFU, by conventional biotechnological methods in the following sequence: selection of a plant donor; procurement of explants; decontamination of the plant material; initiation; multiplication; rhisogenesis and adaptation of the clones to the conditions in vivo [1, 6].

The decontamination of the explants was performed with the following reagents of various concentrations and duration of treatment: flowing water (H_2O) with detergent (8-24 hours), H_2O_2 (3-9 %; 5-15 seconds), C_2H_5OH (50-96 %; 10-30 seconds), NaClO (10-30 %; 3-7 minutes), $AgNO_3$ (0.1 to 0.3 %; 5-15 minutes). After each chemical agent, the explants were washed three times in sterile distilled water. The initiation was carried out in the following modified nutrient media: MS (Murashige and Skoog medium), RW (Risser and White medium), and LM (Litvay medium) (Table. 1).

Multiplication and rooting of the initiated regenerated plants were carried out in the same nutrient media. For the phase of the rhisogenesis, the amount of mineral salts was reduced by half.

Table 1. Modifications of nutrient media for explants initiation

Experiment variant	Medium	Applied phytohormones, mg/l		
		2.4-D	NAA	BAP
1	MS	-	0.1	0.1
2		0.2	-	0.1
3		0.2	0.1	-
4	RW	-	0.1	0.1
5		0.2	-	0.1
6		0.2	0.1	-
7	LM	-	0.1	0.1
8		0.2	-	0.1
9		0.2	0.1	-

The results of studies. Propagation by cuttings. When applying treatment to spring cuttings of T. baccata L.'Fastigiata', the best results are achieved by using the plant growth regulator Kornevin, which provided a 73% rooting. The cuttings treated with water were the worst to root - only 3 %. Similar results were obtained for T. baccata L.'Aurea' – 60 % when using Kornevin, and 13 % when treated with water (Table 2).The propagation of yew and all of its morphological forms by green cuttings shows a low percentage of rooting with the use of all plant growth regulators.

Table 2. The results of propagation by cuttings for the cultivars under study

Species,morphological form	NAA, мg/l			Kornevin	Water
	30	60	90	0.01 %	-
Survival rate,%					
Spring propagation					
T. baccata L. 'Fastigiata'	60	63	60	73	3
T. baccata L. 'Aurea'	40	53	50	60	13
Summer propagation					
T. baccata L. 'Fastigiata'	40	47	33	50	0
T. baccata L. 'Aurea'	30	37	33	43	3

Microcloning. The highest number of sterile explants (97 %) was obtained by the following scheme of decontamination, which implies their sequential treatment by the following reagents: flowing water with detergent (24 hours); a 6 % H_2O_2 (15 minutes); a 70 % C_2H_5OH (30 seconds); a 20 % NaClO (7 min.); and a 0.2 % $AgNO_3$ (15 min.).

The highest percentage of initiated explants of the study ornamental forms of yew was observed in two types of nutrient media: LM and MS modified by phytohormones 2.4-D (0.2 mg/l) + BAP (0.1 mg/l) (Table. 3). Part of the explants had been actively accumulating phytomass up to the 20-25th day of cultivating, after which there was inhibition and, in some cases, cessation of their growth. The other part had been rapidly growing up to the 40-45th day and exceeded the linear size of the first ones almost two times (Figs. 1, 2).

Table. 3.The results of initiation for the investigated forms of yew

No.	The form under investigation	The amount of initiated explants on the 25th day,%		The amount of initiated explants on the 45th day, %	
		LM	MS	LM	MS
1	'Fastigiata'	78	80	76	68
2	'Aurea'	82	76	82	72

The obtained results show that the intensity of the clone initiation for plants under study was the highest when the nutrient medium LM was used.

Fig. 1. Initiation of explant (the 25th day)

Fig. 2. Initiation of explant (the 45th day)

Modifications of nutrient media for multiplication of explants and the results obtained are shown in Table 4.

Table 4. The results of multiplication for the investigated forms of yew

No.	Nutrient medium	Phytohormones			Multiplication indexes			
		2.4-D, mg/l	BAP, mg/l	NAA,mg/l	'Fastigiata'		'Aurea'	
					R, %	n, pcs.	R, %	n, pcs.
1	LM	0.2	0.1	-	50	1.1	44	1.0
2		0.2	-	0.5	48	1.0	48	1.3
3		-	0.1	0.5	54	1.2	50	1.3
4		0.2	0.1	0.5	72	2.2	80	1.3
5	MS	0.2	0.1	-	28	1.0	32	1.0
6		0.2	-	0.5	30	1.1	36	1.1
7		-	0.1	0.5	40	1.0	42	1.0
8		0.2	0.1	0.5	38	1.2	56	1.6

Note: R is the number of explants that formed microshoots; n - average number of micro- shoots formed per explant

The highest percentage of explants that formed shoots was observed in the L M nutrient medium modified by the following phytohormones: 2.4-D (0.2 mg/l), BAP (0.1 mg/l) and NAA (0.5 mg/l). The number of newly formed shoots in this variant of the experiment was also the highest: 'Fastigiata' – 2.2 pcs and the form 'Aurea' – 2.3 pcs. On analyzing the obtained results, we can conclude that the NAA growth regulator is necessary for multiplication of ornamental forms of yew.

Applied modifications of nutrient media for rooting of clones under study and the results obtained are shown in Table 5.

The best root formation was observed in the nutrient medium 1/2 MS + 2.4-D (0.2 mg/l) + NAA (0.5 mg/l), where the following results were obtained: 'Fastigiata' − 68% of rooted explants and 3.0 rootlets, 'Aurea' − 80% of rooted explants and 2.9 rootlets (Figs. 3, 4).

Table 5.The results of explants rooting of the investigated forms of yew

No.	Nutrient medium	Phytohormones		Multiplication indexes			
		2.4-D, mg/l	NAA, mg/l	'Fastigiata'		'Aurea'	
				W, %	n, pcs.	W, %	n, pcs.
1	1/2 LM	0.2	0.5	66	2,.2	66	2.0
2		-	0.5	68	1.6	68	1.8
3		0.2	-	50	1.1	44	1.2
4	1/2 MS	0.2	0.5	68	3.0	80	1.9
5		-	0.5	66	1.9	70	1.7
6		0.2	-	52	1.5	50	1.4

Note: W is the number of explants that formed rootlets; n is average number of rootlets formed per explant.

Fig. 3. Rooted clone

Fig. 4. The adapted clone

After rooting, the clones obtained were removed from the tubes, washed in sterile distilled water off residues of the nutrient medium and transplanted in pre-sterilized substrate (a mixture of soddy soil with sand and peat (1:1:1) and ready-made peat tablets of *Jiffy* brand). Regardles of the morphological differences of the study species, we received, on average, 68 % of viable plants in the first variant and 82 % in the case of using the ready-made peat tablets.

Conclusions. To propagate the ornamental forms of *Taxus baccata* L. by cuttings, it is advisable to use spring cuttings treated with the Kornevin plant growth regulator. Microclonal propagation provides satisfactory results under the following conditions: initiation is advisable to carry out in the nutrient medium LM + 2.4-D (0.2 mg/l) + BAP (0.1 mg/l); multiplication − LM + 2.4-D (0.2 mg/l) + BAP (0.1 mg/l) + (0.5 mg/l); rooting − 1/2 MS + 2.4-D (0.2 mg/l) + NAA (0.5 mg/l).

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УДК 630*174.754 ***Докторант М.М. Лісовий, канд. с.-г. наук – НЛТУ України***

Вегетативне розмноження культиварів *Taxus baccata* l. 'Fastigiata' та 'Aurea'

Проаналізовано низку літературних джерел, які стосуються тематики досліджень. Представлено результати проведених експериментальних досліджень по живцюванню та мікроклонуванню двох культиварів *Taxus baccata* L.: 'Fastigiata' та 'Aurea'. Охарактеризовано основні етапи розмноження методом *in vitro* досліджуваних рослин: деконтамінація експлантів; склад живильних середовищ для ініціації, мультиплікації та укорінення; субстрат для адаптації рослин-регенерантів до ґрунтових умов. Узагальнено та проаналізовано отримані результати.

Ключові слова: *Taxus baccata* L., 'Fastigiata', 'Aurea', живцювання мікроклонування, експлант, стерилізація, ініціація, мультиплікація, живильне середовище.

UDK 630*181.9 ***Dozent V.V. Lavnyy, Dr., Dr. habil. – UNFU, Lviv***

EINFLUSS DER BODENVEGETATION AUF DIE NATURVERJÜNGUNG DER BAUMARTEN AUF DEN STURMWURFFLÄCHEN IN DEN UKRAINISCHEN KARPATEN

Im Artikel sind Ergebnisse einer Untersuchung präsentiert, die den Einfluss von Artenzusammensetzung, Geschlossenheit und Höhe der Bodenvegetation auf den Prozess der Naturverjüngung von Baumarten auf 42 Sturmwurfflächen erfassen, die auf den Territorien von 12 Betrieben mit verschiedenen ökologischen Bedingungen in den Ukrainischen Karpaten liegen. Darin wird festgestellt, daß die größte Anzahl der Sämlinge und Jungwuchs von Baumarten bei hoher Geschlossenheit der Bodenvegetation vorkommt, und zwar beim Wert 1,0 mit 28,3% der gesamten Anzahl vom aufgenommenen Sämlinge und Jungwuchs und beim Wert 0,9 mit 17,1%. Die beste Naturverjüngung von Baumarten auf den Sturmwurfflächen wurde bei der durchschnittlichen Höhe der Bodenvegetation von 20-60 cm ermittelt.

Schlüsselworte: Bodenvegetation, Naturverjüngung von Baumarten, Sturmwurfflächen, Ukrainische Karpaten, Waldökologie.

Eine wichtige Besonderheit der Waldökosysteme besteht in ihrer Fähigkeit zur Selbstverjüngung und Selbstregulation. Eine Schlüsselrolle in diesem Prozess spielt die Naturverjüngung von Baumarten. Aus diesem Grund hat die Untersuchung der Naturverjüngung von Waldbeständen eine große praktische und theoretische Bedeutung. Der Prozess der natürlichen Verjüngung des Waldes wird von vielen Faktoren beeinflusst, von denen wir einige bereits in unseren bisherigen Publikationen dargelegt haben [1-5].

Nachfolgend wollen wir die Auswirkungen der Bodenvegetation auf die Naturverjüngung von Baumarten auf den Sturmwurfflächen analysieren.

Das Ziel unserer Forschung bestand darin, die Auswirkungen der Höhe, Geschlossenheit und Artenzusammensetzung der Bodenvegetation auf den Erfolg bei der Naturverjüngung von Baumarten auf den Sturmwurfflächen in verschiedenen Teilen der ukrainischen Karpaten zu untersuchen.

Forschungsmethodik. Als Grundlage für die Untersuchung von Naturverjüngung der Baumarten auf den Sturmwurfflächen diente die Methode der vergleichenden Ökologie (Vorobyev D.V., 1967; Pogrebnyak P.S., 1968). Der Waldtyp wurde auf der Grundlage der Forst- und Umwelttypologie von Alekseyev und Pogrebnyak (1967, 1968) aufgrund von vergleichbaren Merkmalen bestimmt.

Die Naturverjüngung von Baumarten auf den Sturmwurfflächen ermittelten wir auf der Grundlage eines 2x2 m großen, diagonalen Rasters. Die Stufe der Verjüngungserfolge wurde nach Prof. M.M. Horshenin festgestellt (Tab. 1).

Wenn ein gemischter Jungwuchs von verschiedenem Alter vorhanden war, verwendeten wir Überführungskoeffizienten und bestimmten die Verjüngungserfolge laut der Gruppe von 4-7 Jahren.

Die Koeffizienten betragen:

- für einjährige Sämlinge – 0,15;
- für 2-3 jährige Jungwuchs – 0,6,
- für Jungwuchs von 8 und mehr Jahre – 1,5.

Für jede Probefläche erfassten wir die Höhe über dem Meeresspiegel, die Neigung und Exposition des Hanges, das Jahr des Windwurfs, die Größe der Sturmwurffläche und den Waldtyp. Außerdem charakterisierten wir die benachbarten Bestände.

Tabelle 1. Skala für die Bewertung der Naturverjüngung von Baumarten nach Prof. M.M. Horshenin (Tsd. St. per ha)

Die Stufe	Alter des Jungwuchses, Jahre			
	1	2-3	4-7	8 und mehr
Gut	> 40	> 10	> 6	> 4
Befriedigend	26-40	6-10	3-6	2-4
Ungenügend	15-25,9	3-5,9	1-2,9	0,5-1,9
Unbefriedigend	< 15	< 3	< 1	< 0,5

Die Forschungsobjekte lagen in verschiedenen Teilen der Ukrainischen Karpaten in 12 Betrieben: Staatsbetrieb (SB) "Osmolodske Forstwirtschaft", SB "Vyhodske Forstwirtschaft", SB "Broshnivske Forstwirtschaft", Naturschutzgebiet "Gorgany", Karpatischen Nationalpark, SB "Borynske Forstwirtschaft", Nationalpark "Skolivski Beskydy", SB "Rakhivske forstliche Versuchsbetrieb", SB "Khustske forstliche Versuchsbetrieb", SB "Volovetske Forstwirtschaft", SB "Mizhhirske Forstwirtschaft" und Karpatischen Biosphärenreservat.

Insgesamt haben wir 42 Sturmwurfflächen für die Untersuchung ausgewiesen. Ihre Fläche betrug jeweils zwischen 1,1 und 33,0 Hektar. Die untersuchten Sturmwurfflächen lagen auf verschiedenen Höhen (475-1.250 m ü. NN.) und an den Hängen mit unterschiedlicher Exposition und Neigung (von 0 bis zu 45 Grad).

Ergebnisse der Untersuchung. Die Bodenvegetation hat einen wesentlichen Einfluss auf die natürliche Verjüngung der Baumarten. Deswegen widmeten viele Forscher sowohl in der Ukraine als auch im Ausland ihre Aufmerksamkeit den Fragen nach den Zusammenhängen [2-5]. Die Bodenvegetation bestimmt weitgehend das Umfeld für das Keimen der Samen, das Wachstum und die Entwicklung von Sämlingen und Jungwuchs an den Sturmwurfflächen und hat einen wesentlichen Einfluss auf das Mikroklima der Bodenoberfläche.

Die Auswirkungen der Bodenvegetation auf den Fortschritt der natürlichen Regeneration von Waldbäumen können sowohl positiv als auch negativ sein. Einerseits werden unter dem Schirm der Bodenvegetation junge Bäumchen vor Frost und Sonnenbrand geschützt. Außerdem reduziert sich die Verdampfung in der Bodenoberfläche. Auf der anderen Seite ist die Bodenvegetation für Sämlinge ein Konkurrent für Licht, Feuchtigkeit und Mineralstoffernährung. Darüber hinaus wirkt die Grasnarbe negativ. Besonders das Land-Reitgras (*Calamagrostis epigeios (L.) Roth.*), Rasen-Schmiele (*Deschampsia cespitosa (L.) Beauv.*) und Borstgras (*Nardus stricta L.*) beeinträchtigen oder verhindern den Prozess der Wiederbewaldung. Während der Aufnahme der Baumartenverjüngung auf den Sturmwurfflächen in den Ukrainischen Karpaten bestimmten wir auf den Erfassungsquadraten auch die Geschlossenheit und die durchschnittliche Höhe der Bodenvegetation. Die Verteilung der Gesamtzahl von Sämlingen und Jungwuchs der Baumarten auf allen Erfassungsflächen in Abhängigkeit von der Geschlossenheit der Bodenvegetation ist auf der Abb. 1 dargestellt.

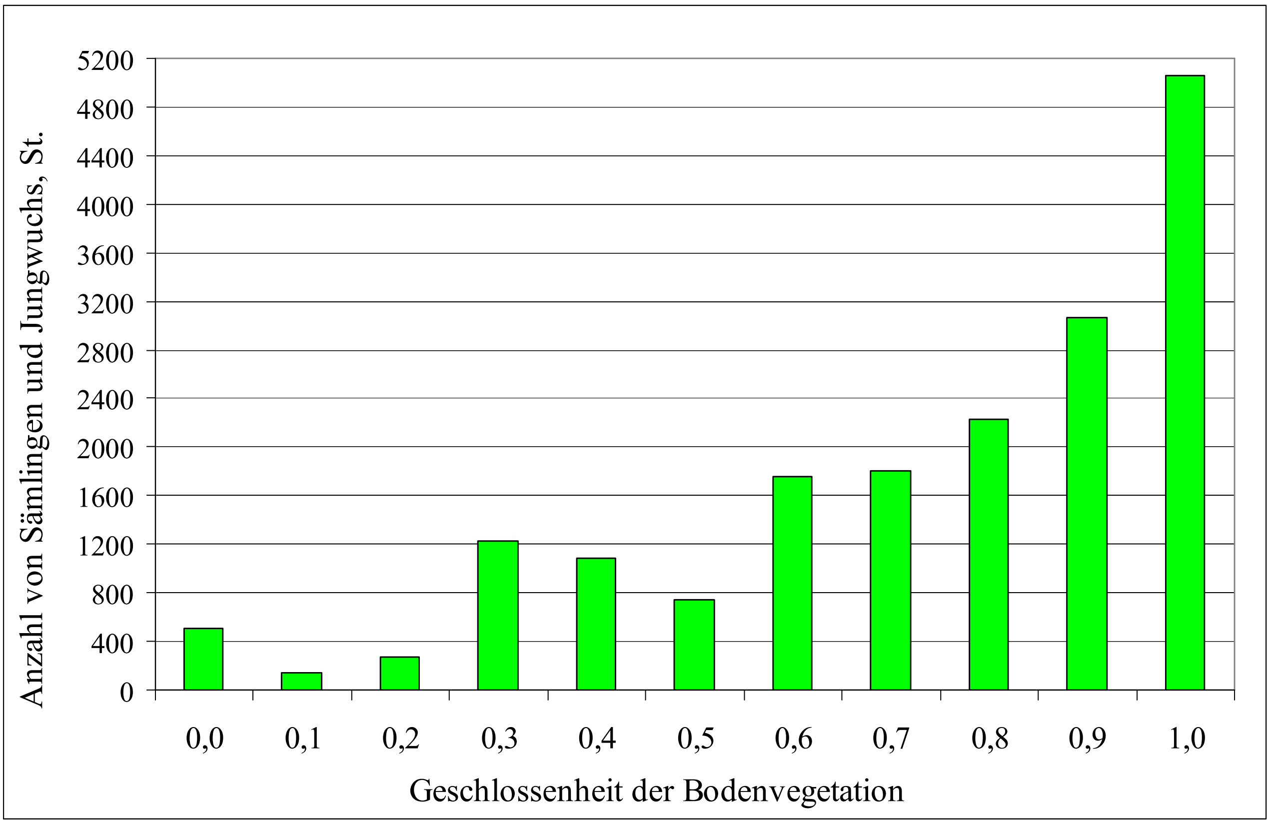

Abb. 1. Verteilung der gesamten Anzahl von Sämlingen und Jungwuchs der Baumarten auf den Sturmwurfflächen in den Ukrainischen Karpaten ist abhängig von der Geschlossenheit der Bodenvegetation

Die Analyse der Abb. 1 zeigt, dass die größte Anzahl der Sämlinge und Jungwuchs von Bäumen auf den Sturmwurfflächen in den Ukrainischen Karpaten bei der hohen Geschlossenheit der Bodenvegetation ermittelt wurde. Dort haben wir auf den aufgenommenen Erfassungsflächen mit der Geschlossenheit der Bodenvegetation 1,0 die gesamte Anzahl von Sämlingen und Jungwuchs mit 28,3% erfasst. Auf den Flächen mit der Geschlossenheit der Bodenvegetation 0,9 wurden 17,1% von Sämlingen und Jungwuchs registriert und bei der 0,8 waren es 12,5%. Dies beruht auf einem positiven Einfluss von Bodenvegetation auf das Wachstum von Sämlingen und Jungwuchs, da diese das Mikroklima auf den Sturmwurfflächen verbessern (Schutz gegen Sonnenbrand, Frost, Wind und extreme Temperaturen). Doch neben der Geschlossenheit der Bodenvegetation wirken sich auf den Prozess der natürlichen Regeneration von Baumarten auf den Sturmwurfflächen noch viele andere Faktoren aus.

Die Verteilung der Gesamtzahl von Sämlingen und Jungwuchs der Baumarten auf den Sturmwurfflächen ist abhängig von der durchschnittlichen Höhe der Bodenvegetation und in Abb. 2 dargestellt.

Aus der Abb. 2 ist zu sehen, dass keine direkte Korrelation zwischen der durchschnittlichen Höhe von der Bodenvegetation und der Anzahl von Sämlingen und Jungwuchs der Baumarten auf den Sturmwurfflächen besteht. Im Ergebnis wurde die größte Anzahl von Sämlingen und Jungwuchs auf den Erfassungsflächen mit der durchschnittlichen Höhe von Bodenvegetation 20-60 cm beobachtet. Und zwar bei der mittleren Höhe der Bodenvegetation von 20 cm wurden 14,6% der Sämlinge und Jungwuchs aufgezeichnet, bei deren Höhe von 30 cm – 16,9%, 40 cm – 14,6%, 50 cm – 15,9% und 60 cm – 16,0%. Bei einer größeren Höhe der Bodenvegetation auf den Sturmwurfflächen dominieren Himbeeren, die die Sämlinge und Jungwuchs von Bäumen unterdrücken.

Die Ergebnisse unserer Untersuchung zeigen, dass die Artenzusammensetzung der Bodenvegetation auf den Sturmwurfflächen weitgehend vom Waldtyp, dem Gestein, der Größe und Konfiguration der Sturmwurffläche, deren Höhe über dem Meeresniveau, der Exposition und Steilheit des Hanges, dem Vorhandensein und der Dichte der den Sturm überlebenden Bäume und anderen Faktoren abhängt.

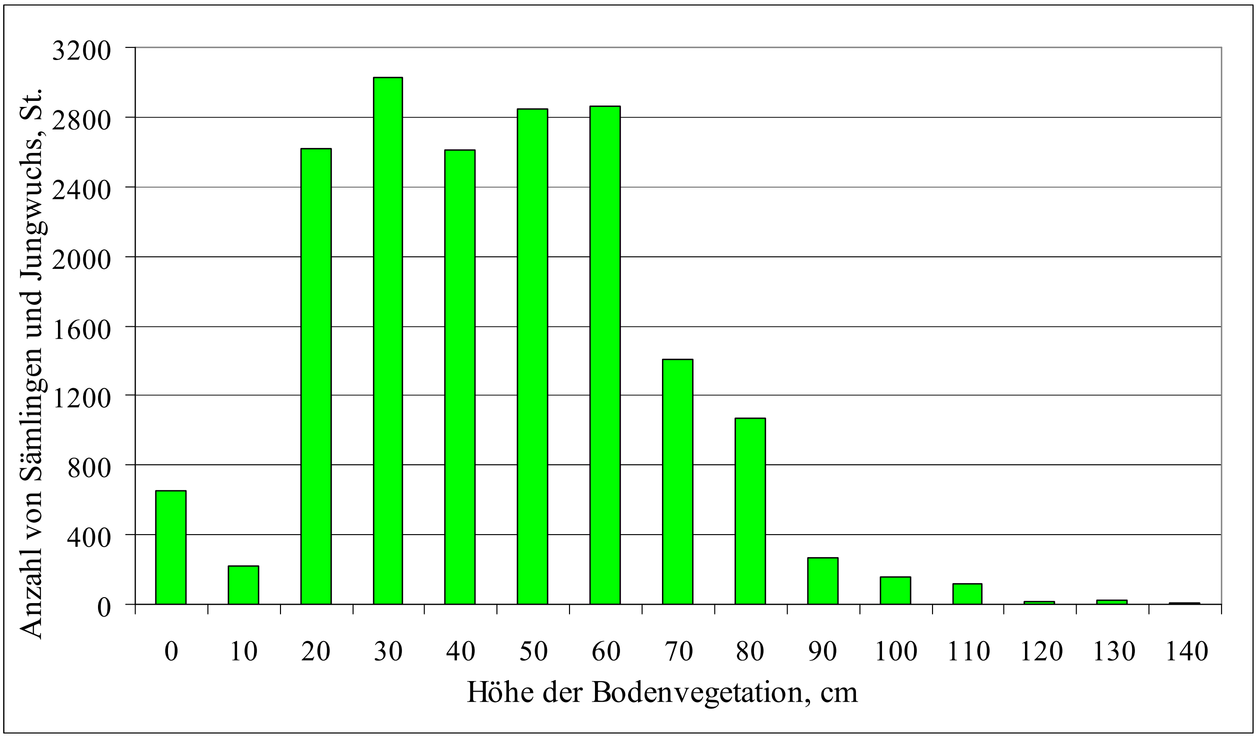

Abb. 2. Verteilung der gesamten Anzahl von Sämlingen und Jungwuchs der Baumarten auf den Sturmwurfflächen in den Ukrainischen Karpaten abhängig von der mittleren Höhe der Bodenvegetation

Die Artenzusammensetzung der Bodenvegetation auf den Sturmwurfflächen ist ziemlich reich und vielfältig. Unter der Pflanzen dominieren folgende Arten: *Rubus caesius L.*, *Luzula sylvatica L.*, *Deschampsia caespitosa (L.) Beauv.*, *Vaccinium myrtillus L.*, *Rubus idaeus L.*, *Oxalis acetosella L.*, *Molinia caerulea (L.) Moench.*, *Mycelis muralis (L.) Dumort.*, *Mercurialis perennis L., Carex sylvatica Huds.*, *Athyrium filix-femina L., Dryopteris filix-mas L., Senecio fuchsii L., Dentaria glandulosa L., Dentaria bulbifera L., Chamaenerium angustifolium Scop.*, *Glechoma hederacea L.*, *Calamagrostis epigeios (L.) Roth.*, *Fragaria vesca L., Nardus stricta L., Prenanthes purpurea L., Melampyrum nemorosum L., Galeodolon luteum Huds., Stellaria holostea L., Festuca altissima All., Impatiens noli-tangere L., Hypericum perforatum L.*, **Agrostis gigantea** *Roth.*, *Silene nutans L.*, *Gallium odoratum (L.) Scop., Carex sylvatica Huds., Anemone nemorosa L.,* in den Niederungen – *Scirpus sylvaticus L., Juncus effusus L., Polygonum hydropiper L., Matteuccia struthiopteris* L., *Petasites albus (L.) Gaertn., Carex acutiformis Ehrh.* und *Geum rivale L.*

Die Moosschicht kommt in der Regel nicht flächendeckend vor, die Moossyntope sind voneinander getrennt. Unter der Bryoflora dominieren folgende Arten: *Polytrichum commune Hedw., Sphagnum* **species**, *Dicranum scoparium Hedw., Hylocomium splendens (Hedw) B.S.G.*, *Eurhynchium striatum (Hedw.) Schimp., Rhytidiadelphus triquetrus (Hedw.) Warnst., Hypnum cupressiforme Hedw.* ***und*** *Atrichum undulatum (Hedw.) Beauv*.

Abb. 3. Das Wald-Weidenröschen auf der Sturmwurffläche im Staatsbetrieb "Vyhoda Forstwirtschaft"

Besonders negative Auswirkung haben Brombeere und Himbeere auf die Naturverjüngung in den Sturmwurfflächen. Mit ihrer Verbreitung verschlechtern sich die Bedingungen für die Keimung und das Wachstum von Sämlingen und Jungwuchs. In Bereichen des dichten Vorkommens von Brombeeren und Himbeeren läuft der Prozess der natürlichen Verjüngung von Baumarten nur sehr langsam. Auf solchen Flächen werden

Jungbestände mit ungleichmäßiger Dichte und lichtem Kronenschluss gebildet. Die Wachstumsbedingungen der jungen Bäume und die zu erwartende Bestandsqualität sind erheblich verschlechtert. Daher ist das erste Jahr entscheidend für die Sicherung der guten Baumartenverjüngung auf frischen Sturmwurfflächen, bevor sich Brombeeren und Himbeeren dort etablieren können.

Das Wald-Weidenröschen (*Chamaenerium angustifolium Scop.,* Abb. 3*)* hat auf den Sturmwurfflächen vorwiegend einen positiven Einfluss auf die Verjüngung des Waldes. Es verbessert die physikalischen und chemischen Eigenschaften des Bodens. Außerdem verhindert diese Pflanzenart die Verbreitung von Graspflanzen und Himbeeren auf den Flächen.

Zum positiven Einfluss der Bodenvegetation gehört auch die Minderung der Verdunstung von Bodenfeuchte sowie der Schutz der Sämlinge und Jungwuchs vor dem Sonnenbrand. Letzteres ist in den Gebirgen sehr wichtig, vor allem auf den steilen und sehr steilen Hängen, wo nahezu senkrechte Sonneneinstrahlung schon früh im Sommer oft den Sonnenbrand an jungen Bäumchen verursacht.

Schlussfolgerungen. Die Bodenvegetation hat auf den Sturmwurfflächen einen bedeutenden Einfluss für die Naturverjüngung der Baumarten. Sie bestimmt im großen Maße das Umfeld für die Keimung von Baumsamen und das Wachstum von Sämlingen. Der Einfluss der Bodenvegetation kann sowohl positiv als auch negativ sein.

Die Ergebnisse unserer Untersuchung haben gezeigt, dass die größte Anzahl der Sämlinge und Jungwuchs von Baumarten auf den Sturmwurfflächen in den Ukrainischen Karpaten bei dichter Geschlossenheit der Bodenvegetation erfasst wurde. Bei der Geschlossenheit der Bodenvegetation 1,0 wurden 28,3% der gesamten Anzahl von aufgenommenen Sämlingen und Jungwuchs gemessen.

Es wurde kein direkter Zusammenhang zwischen der durchschnittlichen Höhe der Bodenvegetation und der Anzahl von Sämlingen und Jungwuchs auf den Sturmwurfflächen festgestellt. Im Ganzen wurde die größte Anzahl von Sämlingen und Jungwuchs auf den Erfassungsflächen mit der mittleren Höhe von Bodenvegetation 20-60 cm beobachtet. Im Allgemeinen sind auf der Mehrzahl der Sturmwurfflächen in den Ukrainischen Karpaten unter Sämlingen und Jungwuchs in beträchtlicher Zahl die Hauptbaumarten des umgebenden Waldtyps vertreten. Sie können zur künftigen Bildung von Primärbeständen entsprechend den Waldtypen beitragen.

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УДК 630*181.9 ***Доц. В.В. Лавний, д-р с.-г. наук – НЛТУ України***

Вплив живого надґрунтового покриву на природне поновлення деревних порід на вітровальних ділянках в Українських Карпатах

Представлено результати дослідження впливу видового складу, зімкнутості та висоти живого надґрунтового покриву на процес природного поновлення деревних порід на 42 вітровальних ділянках, що були розташовані у різних екологічних умовах на території 12 підприємств. Встановлено, що найбільша кількість самосіву і підросту деревних порід спостерігалася при високій зімкнутості живого надґрунтового покриву, зокрема при його зімкнутості 1,0 було зафіксовано 28,3% від загальної кількості самосіву і підросту, а при 0,9 - 17,1%. Найкраще природне поновлення деревних порід спостерігалося при середній висоті живого надґрунтового покриву 20-60 см.

Ключові слова: живий надґрунтовий покрив, природне поновлення деревних порід, вітровальні ділянки, Українські Карпати, лісознавство.

UDC 630*181.9 ***Assoc. prof. V.V. Lavnyy, Dr., Dr. habil. – UNFU***

The influence of the ground cover on the natural regeneration of tree species on windthrow areas in the Ukrainian Carpathians

The article present the research results of the influence of species composition, canopy density and height of the ground cover on the process of natural regeneration of tree species on 42 windthrow areas in the Ukrainian Carpathians, that were located in different ecological conditions in 12 enterprises. It was established that the greatest number of self-seeding and underwood of trees occurs by the high canopy density of the ground cover, particularly by 1.0 was recorded 28.3% of self-seeding and underwood, and by 0.9 - 17.1%. The best natural regeneration of tree species were observed by the average height of the ground cover 20-60 cm.

Keywords: the ground cover, natural regeneration of tree species, windthrow areas, the Ukrainian Carpathians, forest ecology.

ДО ВІДОМА АВТОРІВ СТАТЕЙ

При підготовці статей для міжвідомчого науково-технічного збірника "**Лісове господарство, лісова, паперова і деревообробна промисловість**" радимо авторам дотримуватись таких рекомендацій.

Автор поданої до друку статті повинен чітко уявити коло читачів, на яке він розраховує. Рекомендуємо дотримуватись деяких загальних правил побудови науково-технічної статті: чітко і зрозуміло сформулювати постановку задачі; доступно викласти методику її розв'язання; зробити висновки науковцям або дати практичні рекомендації виробничникам.

Наукова праця повинна містити необхідні характеристики описаних конструкцій чи схем, але в ній не має бути ні зайвого опису історії питання, ні відомих з підручників ілюстрацій, даних, математичних викладок.

Текст статті обсягом 5-20 сторінок необхідно подавати українською чи будь-якою іншою мовою, друкувати на папері формату А4 за допомогою комп'ютера у редакторі MS Word (шрифт – Times New Roman, розмір – 14 points, рядки – через 1.5 інтервали, поля – 2 см по периметру) без присвоєння жодних стилів і оформляти в такій послідовності. На початку статті **ОБОВ'ЯЗКОВО** проставляється індекс УДК (Універсальної десяткової класифікації), в заголовку українською мовою вказуються: вчене звання, ініціали і прізвище автора (або авторів), науковий ступінь, скорочена назва закладу, в якому виконана робота, назва статті, анотація (500 знаків) та ключові слова. Далі – англійською мовою: ініціали і прізвище автора (або авторів), скорочена назва закладу, в якому виконана робота, назва статті, анотація та ключові слова.

Сторінки рукопису нумеруються, а на полях олівцем вказуються місця ілюстрацій і таблиць, якщо останні додаються до статті на окремих аркушах. Особливу увагу необхідно звернути на акуратний набір формул, індексів і показників, з використанням можливостей редактора MS Equation.

При підготовці рукопису необхідно користуватися науково-технічними термінами відповідно до діючих стандартів на термінологію, наведений матеріал не повинен дублювати таблиці. Скорочення слів, імен, назв у тексті статті не допускаються. Можливе використання тільки загальноприйнятих скорочень - мір (тільки після цифр), хімічних, фізичних і математичних величин. Назви установ, підприємств, марки механізмів і т.д., що згадуються в тексті статті вперше, необхідно писати повністю (вказуючи в дужках скорочену назву); надалі ця назва може зустрічатися у скороченому вигляді.

У таблицях необхідно точно вказувати одиниці фізичних величин, у назвах граф слова скорочувати небажано. Таблиці необхідно виконувати переважно вздовж листа з максимальною насиченістю інформації в рядках. Надто громіздких таблиць складати не рекомендується.

Ілюстрації (фотографії та рисунки) до статті подаються в одному примірнику. Фотографії повинні бути контрастні, розміром не менше 9x12 см, рисунки розміром не більше стандартного листка, виконані чорною тушшю пером на якісному папері. Допускається подання рисунків у форматі *.cdr (редактор CorelDRAW), у форматі *.tif або *.jpg (редактор PhotoShop, 300 dpi, b/w або Grayscale) чи оформлених у середовищі MS Excel. У тексті статті посилання на ілюстрації беруться в круглі дужки, позиції на рисунках розташовуються за годинниковою стрілкою і повинні відповідати наведеним у тексті. Окремо подані ілюстрації на зворотній стороні нумеруються і підписуються олівцем.

При посиланні в тексті статті на роботи інших авторів у квадратних дужках вказують номер позиції списку літератури, яка подається в кінці статті. Список літератури оформляється згідно з вимогами і правилами складання бібліографічного опису документа. У випадку наведення цитати необхідно вказати, звідки вона взята (автор, назва роботи, номер тому, рік видання, сторінки).

У кінці статті додаються такі матеріали: **прізвища та ініціали авторів, назва статті; заява зі вказуванням для кожного автора вченого звання та наукового ступеня, посади, повної та скороченої назви закладу, де виконана робота, службової чи домашньої адреси, номери телефонів, E-mail, прізвища авторів для листування.** Окрім того, необхідно подати витяг з протоколу засідання кафедри про можливість публікації статті, експертний висновок, дві рецензії - внутрішню і зовнішню. Також вказується кількість примірників збірника, які автор хотів би отримати з опублікованою його статтею.

Старанно вивірений текст статті підписується автором, проставляється дата відправлення чи подання. Редакція може повернути авторові неохайно оформлену статтю, має право проводити редакційні виправлення. До редакції надсилається (приноситься) один роздрукований примірник статті та CD-диск з її текстом. Авторові (авторам) однієї статті видається один збірник з публікацією.

У наступних роках запрошує до спілкування працівників лісового і деревообробного комплексу, співробітників середньо-технічних, вищих навчальних і науково-дослідних закладів, науковців з-за кордону.

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Збірник науково-технічних праць

ЛІСОВЕ ГОСПОДАРСТВО,
ЛІСОВА, ПАПЕРОВА І ДЕРЕВООБРОБНА
ПРОМИСЛОВІСТЬ

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