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Analysis of the influence of larch fibers and particles on selected properties of fiber- and particleboards

BARTŁOMIEJ PAZIO[1], PIOTR BORUSZEWSKI[2]
[1] Warsaw University of Life Sciences – SGGW, Faculty of Wood Technology
[2] Warsaw University of Life Sciences – SGGW, Institute of Wood Sciences and Furniture, Department of Technology and Entrepreneurship in Wood Industry

Abstract: *Analysis of the influence of larch fibers and particles on selected properties of fiber- and particleboards.* The paper presents the results of the research on the effect of the addition of fibers and particles obtained from European larch wood (*Larix decidua* Mill) from plantations on selected properties of fiber- and particleboards in comparison to the boards of the same structure based on typical industrial raw material (pine wood) uses by European wood based panels industry. The differences were shown in the tests, i.e.: modulus of rupture (MOR), modulus of elasticity in static bending (MOE), internal bond (IB), thickness swelling after 2 and 24 hours soaking in water and density profile. In the MOR and MOE tests, larch boards with a minimum 50% fiber share were characterized by comparable values of the properties determined to pine boards, while in the other variants, boards made of pine wood had better properties. In most cases, the larch boards were characterized by significantly lower values of swelling by thickness (with the exception of boards made of fibers) than boards made of wood from forest cultivation. The density profile of the boards on the cross-section of the plantation raw material did not differ from the boards made of pine raw material.

Key-words: European larch, plantations, plantation cultivation, particle-fibrous boards, properties of wood-based boards

INTRODUCTION

In 2017, the total amount of timber harvested in the world was 3823 million m^3, which equates to approximately 0.50 m^3 per person (GUS 2019). The harvesting of wood from forests increases every year. Because of the increasing demand for this raw material. According to FAO experts' reports, around 2060 the indicator of annual demand for wood raw material will be approximately 1 m^3 per person (Zwoliński 2008). In Poland, timber harvesting is much higher per person than the global average. In 2017, 45.3 million m^3 of wood was harvested in Poland, which is approx. 1.19 m^3/person (GUS 2019). In recent years, there has been a high dynamics of growth in demand for wood raw material in the world. A similar trend is also observed in Poland, hence there is a real risk associated with the deficit of wood raw material for the industry based on its processing. New solutions should be sought out in order to eliminate the emerging problem of raw material deficiency. One of the possibilities may be to adapt the raw material form plantations to wood processing (Keegan *et al.* 1992; Pilate *et al.* 1999; Johansson 2013). The development of large-scale plantations and agroforestry systems is important to meet demand and reduce forest wood shortages (Fujiwara and Yang 2000).

The wood-based panels industry is characterized by a high level of development. The basic assumptions of the technological processes remain unchanged, whereas the modernization of individual stages of the production of panels is constantly introduced in terms of improving production efficiency, increasing the level of its environmental friendliness as well as increasing the level of hygiene of the materials produced. In 1997, the panel production worldwide amounted to 152.4 million m^3, and in 2017 this value increased to 401.5 million m^3. On a global scale, the largest producers of wood-based panels in 1997 were: the United States with a global production share of approx. 26%, Germany with a 7.5%

share, Canada with a 7% share. However, in 2017 the situation changed: China with a 50% share, United States - 7% share, Russia - 4% share (Hikiert 2019).

The continuous increase in the production of wood-based panels has led to the development of many innovations, especially with regard to the diversification of the raw material base and the ways of processing new materials. In 2015, the WanhuaEcoboard plant, in agreement with Dieffenbacher, launched the production of straw-based chipboard, which is constantly developed (Nicewicz 2019). Other examples of alternative raw materials in the production of panels are: basket willow (*Salix vimnalis* L.) (Warmbier *et al.* 2011), corn cobs (Sekaluvu *et al.* 2014, Banjo Akinyemi *et al.* 2016), giganteus miscanthus (Pawlak *et al.* 2018), sunflower husk (Klimek *et al.* 2016), as well as the wood of fruit trees, from which about 71% is apple wood (Auriga *et al.* 2019; Łączyński *et al.* 2016).

Plantation crops are usually monocultures where one or more species of trees with similar soil requirements are cultivated. According to some sources, species that grow fast in the cycle of up to 50 years should achieve an average annual volume increase of over 12 m^3/ha per year (Dimitri 1981). In Poland, 8 m^3/ha per year is assumed as the minimum average increment determining the profitability of plantation crops for trees aged 40-60 (Zajączkowski, Załęski 1993). Therefore, the thesis by Hejmanowski (1969) was rightly put forward that the concept of a rapidly growing tree is a relative term that is not always reflected in reality.

Due to the relatively high durability, fast-growing character and high adaptability, European larch (*Larix decidua* Mill.) is a promising species of plantation trees (Ritchie 1991). The value of the average annual growth for European larch from plantations is twice as high as for European larch from typical crops. It has been shown that the structure of larch wood from plantations differs from that of forest wood. Wood from plantations has much wider annual increments than wood from forest crops (Boruszewski *et al.* 2017); therefore, it shows a higher proportion of earlywood, lower density, shorter cell length, thinner cell wall, and greater cell lumen (Rendle 1959).

This paper presents research on the use of European larch wood (*Larix decidua* Mill.) from plantations as a raw material for the production of particleboard, fiberboard, and particle-fibrous boards. This species, due to its relatively high durability, fast-growing character and high adaptability, is considered to be the future of fast-growing plantation trees (Ritchie 1991).

AIM AND SCOPE OF THE STUDY

The aim of the study is to determine to what extent the addition of fibers and particles obtained from European larch wood (*Larix decidua* Mill.) from plantation crops influences selected properties of fiber- and particleboards, compared to boards of the same structure based on typical wood raw material (*Pinus sylvestris* L.) uses by European wood based panels industry.

The scope of the study includes:

- acquisition and preparation of wood raw material;
- determination of the unit formula of urea-formaldehyde glue used in the production of fiber- and particleboards;
- production of 10 variants of fiber- and particleboard forms on a laboratory scale;
- seasoning of board forms produced according to the assumptions of individual variants;
- preparation of samples for determination of:
    - ✓ modulus of rupture (MOR),
    - ✓ modulus of elasticity in static bending (MOE),
    - ✓ internal bond (IB),

- ✓ thickness swelling (TS) after soaking in water for 2 and 24 hours;
- analysis of the obtained test results, successively determining the influence of the type of raw material and the share of wood particles and fibers on selected properties of particle-fibrous boards.

MATERIAL AND METHODOLOGY

In the planned tests, single-layer particleboard, particle-fibrous and fibrous boards were produced with a varied proportion of wood particles, obtained from:

- Scots pine (*Pinus sylvestris* L.) with medium density 480 kg/m^3,
- European larch from plantation (*Larix decidua* Mill.) with medium density 390 kg/m^3.

The wood particles used for the production of boards were obtained in industrial conditions on the process lines producing particleboards and MDF. For the production of boards, fractions used as standard in industrial conditions were used (as single-layer boards were produced in the work, in the case of boards containing wood particles, particles' fractions used for the core layer were used).

According to the specifications in table 1 in total, 10 variants of panels (5 panels produced for each variant) were produced with target density of 600 kg/m^3 and nominal dimensions length 320 mm, width 320 mm, thickness 12 mm.

Table 1. Characteristics of variants of the manufactured boards

Variant	Wood raw material	Share by weight of wood particles	Share by weight of wood fibers
1	Larch	100%	0%
2		75%	25%
3		50%	50%
4		25%	75%
5		0%	100%
1'	Pine	100%	0%
2'		75%	25%
3'		50%	50%
4'		25%	75%
5'		0%	100%

Urea-formaldehyde glue with a concentration of 50% was used to glue the wood particles (the glue content was set at 10%). The available 10% aqueous solution of ammonium chloride was used as a hardener for urea-formaldehyde resin. The hardener content was selected for a gel time of 100 seconds. The moisture content of the fibers and particles used to manufacture the boards was 5% (± 1%). As a hydrophobic agent, a paraffin in the form of a paraffin emulsion with a concentration of 50% was used (the paraffin content was 1% in relation to the completely dry weight of particles/fibers). The wood particles and/or fibers were glued in sealers together (separately for each variant panel), into which glue and paraffin were injected using a pneumatic spray. A mat was manually formed from the glued wood particles using a forming box, after removing the forming box the formed mat placed between two metal sheets and pressed in a laboratory press using the following parameters:

- temperature of press platens: 180˚C;
- pressing factor: 18 s/mm (total pressing time: t_p = 216s);
- maximum unit pressure: p_{max} = 2.5 MPa, the pressure was reduced in a function of time at:

- maximum unit pressure: $t_1 = 0.5 \times t_p$,
- 2/3 maximum unit pressure: $t_2 = 0.7 \times t_p$,
- 1/3 maximum unit pressure: $t_3 = 0.9 \times t_p$.

After pressing process, boards were seasoned at a temperature of 21°C (±2°C) and air humidity of 65% (±5%) for 2 weeks in order to obtain a moisture content of 10%. Then the boards were cut to size according to the specifications of the relevant standards for testing:

- MOR: according to PN-EN 310,
- MOE: according to PN-EN 310,
- IB: according to PN-EN 319,
- TS after soaking in water: according to PN-EN 317.

In addition, the density profile of the boards on the cross-section was determined using a DA-X analyzer from GreCon (Fagus-Grecon Greten GmbH & Co. KG, Alfeld-Hannover, Germany) with a scanning accuracy of 0.02 mm, and a sample speed of 0.05 mm/s.

Statistical analysis of the obtained test results was determined using Statistica v. 10 software (TIBCO Software Inc., Palo Alto, CA, USA). Data were analysed and provided as the mean ± standard deviation, the scatter plot of results around the median, and minimum and maximum values. To compare and determine the significance of difference between data, t-test was used.

RESULTS AND ANALYSIS

Table 2 summarizes the results of the average density of panels manufactured according to the assumptions of each variant. The obtained differences in the density of boards in relation to the assumed density were statistically insignificant (the coefficient of variation in individual board variants ranged from 0.1% to 0.5%).

Table 2. List of obtained densities for individual panel variants

Variant	Density [kg/m^3]	Standard Deviation [kg/m^3]	Coefficient of Variation [%]
1	606	0.71	0.12
2	602	2.12	0.35
3	605	1.41	0.23
4	605	2.83	0.47
5	604	0.71	0.12
1'	606	1.41	0.23
2'	608	1.41	0.23
3'	606	0.00	0.00
4'	604	2.83	0.47
5'	608	2.12	0.35

Figure 1 shows the values of modulus of rupture for boards made of plantation larch wood and for boards made of typical raw material - pine wood. Standard deviation from the mean strength values did not exceed 1.5 N/mm^2, whereas the coefficient of variation was below 10% in all variants. When analyzing the obtained results, it can be seen that in the case of variants 1 and 1' (100% particles) and 2 and 2' (75% particles, 25% fibers) the differences in the values of the determined strength were statistically significant. Therefore, it should be concluded that the boards made of larch particles or with their share at the level of 75% are characterized by a lower value of modulus of rupture than boards based on the typical raw material - pine wood. In the remaining variants (with the increase in the content of fibers), the differences between the values of the determined strength of the boards, regardless of the type of raw material used for their production, were statistically insignificant.

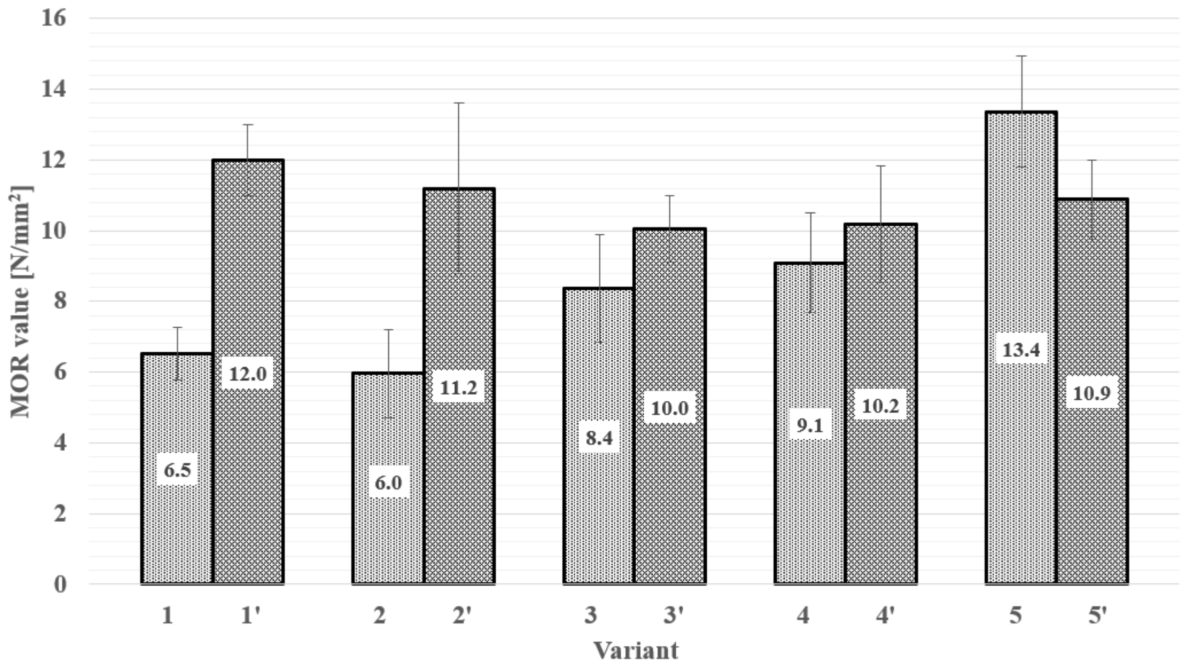

Figure 1. The values of modulus of rupture for the manufactured panel variants

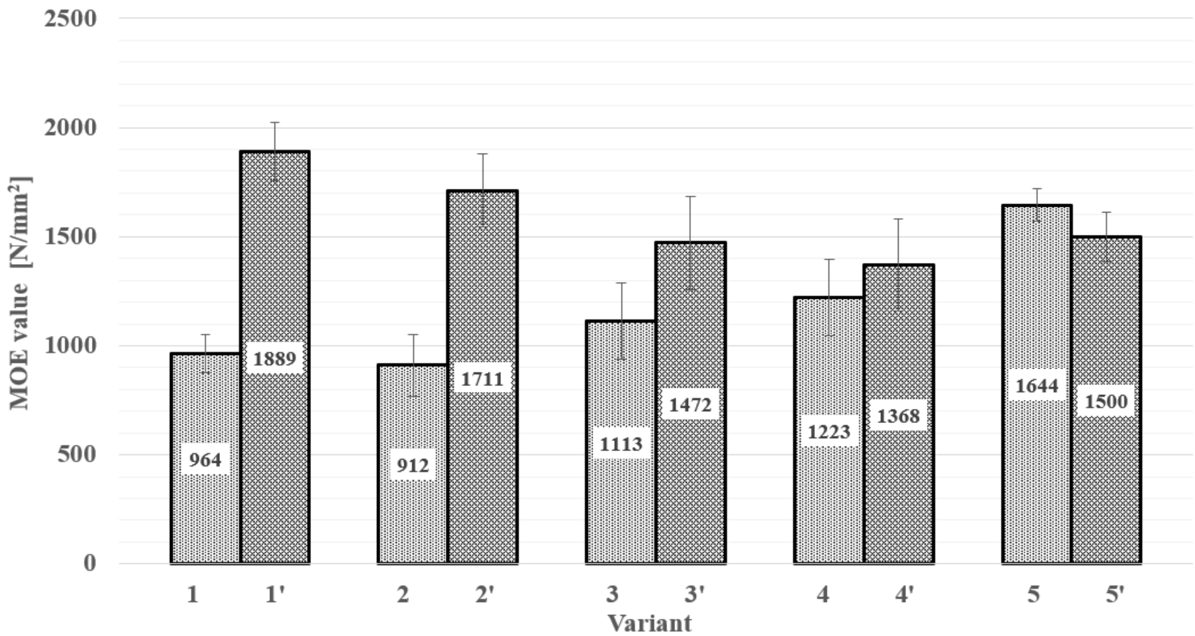

Figure 2. Values of the modulus of elasticity for the manufactured panel variants

Figure 2 shows the obtained values of the modulus of elasticity in static bending for the tested panels. The standard deviation from the mean strength values did not exceed 200 N/mm^2, whereas the coefficient of variation for each variant was below 15%.

The presented values show that in the variants made of wood particles and with their share at the level of 75%, the differences in the obtained values of the elasticity modulus were statistically significant - boards based on typical raw material, i.e.: pine, are characterized by a higher value of the determined strength compared to boards made with larch raw material. Along with the gradual increase in the proportion of fibers, the differences between the values of the modulus of elasticity of the boards, regardless of the type of raw material used for their production, were statistically insignificant.

The presented figure 3 shows that the share of particles made of European larch wood in the boards improves the internal bond. Moreover, the obtained test results show that the higher proportion of fibers in the board, the lower values of internal bond. In this case, the fibrous mats could be overheated more efficiently than particles mats, and with the additional use of plantation wood, which is characterized by low density (Boruszewski *et al.* 2017), it made it difficult to remove moisture from the mat during pressing. In turn, this could translate into a decrease in the determined strength (during the pressing of the mat, steam discharge was significantly impeded), because during the pressure reduction and opening of the press, the water vapor contained in the mat most likely expanded too much, which significantly weakened the adhesive joints between individual fibers (Boruszewski *et al.* 2016). Pressing of the mats made of low-density wood particles requires changing the process parameters (i.e. the pressure and temperature regime) (Moslemi 1974).

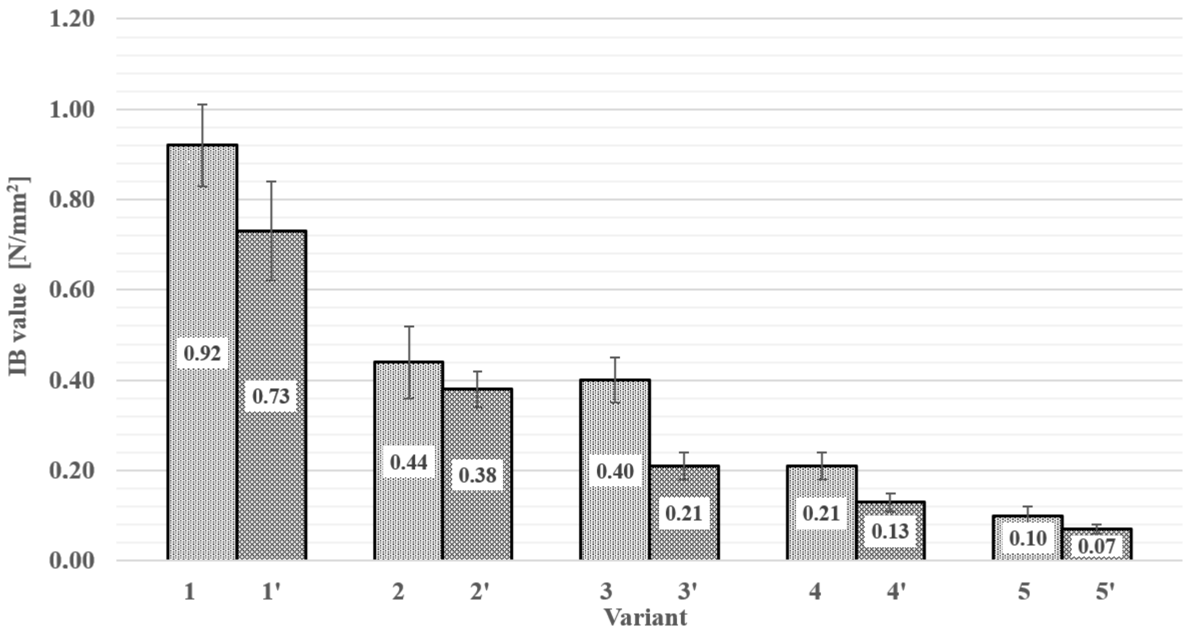

Figure 3. Internal bond values for the tested boards

Figure 4 shows the thickness swelling of the boards after soaking in water for 2 and 24 hours. The standard deviation from the expansion values did not exceed 5%, whereas the variability rate for each variant was below 18%. When analyzing the obtained results, it can be noticed that the differences in the average swelling value between the variants of panels made of larch and typical raw materials are statistically significant both after 2 and 24 hours of soaking in water. In the case of soaking, it should be noted that the boards made of larch particles after 2 and 24 hours are characterized by lower thickness swelling values than boards based on the typical raw material - pine wood. Only in the case of fiber boards, the boards based on pine wood were characterized by a lower value of thickness swelling.

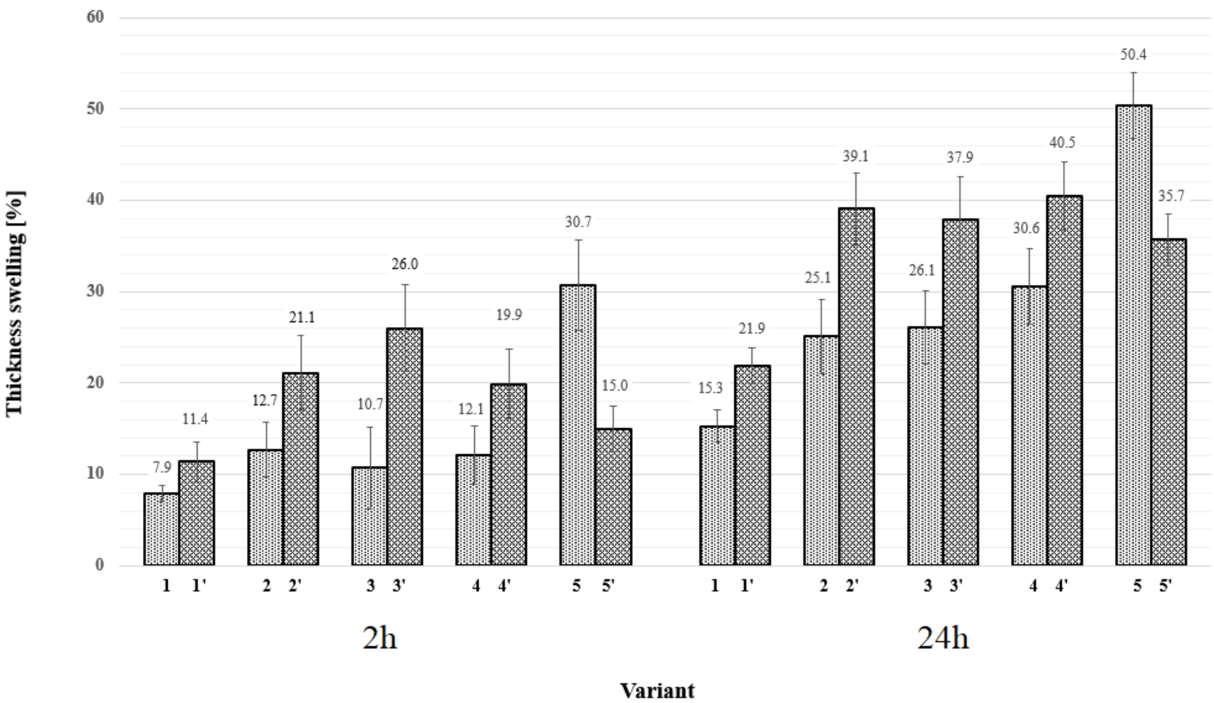

Figure 4. Thickness swelling after 2 and 24 hours of soaking in water

Density profile

The obtained density profiles on the cross-section of boards manufactured according to the assumptions of individual variants (Figure 5 and 6) in all cases assumed the U-shaped course, typical for boards with fibrous and particles structure (Thoemen *et al.* 2010). Single-layer boards show lower density differentiation than three-layer boards whose cross-sectional density difference can reach even 500 kg/m^3 (Wong *et al.* 2000).

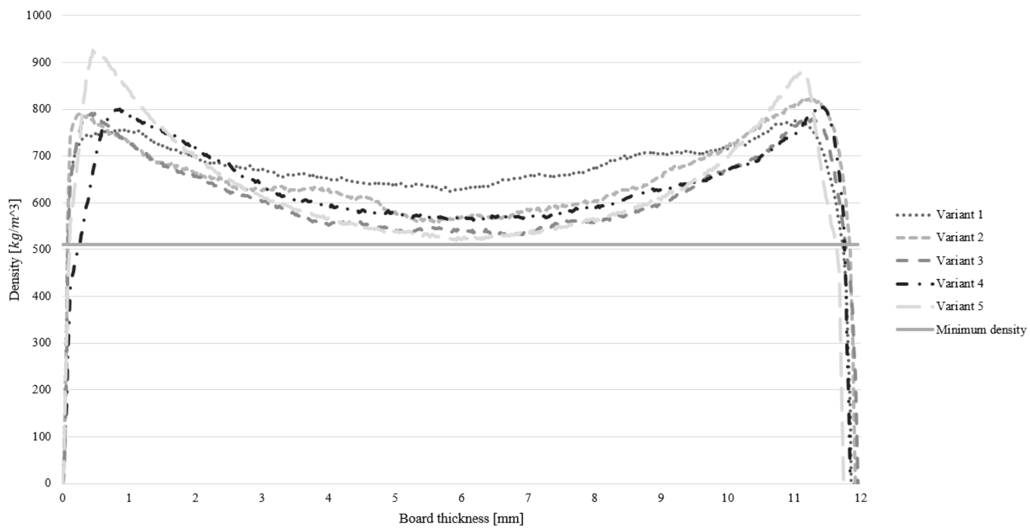

Figure 5. Density profile for each of the variants of larch boards

The manufactured boards were characterized by low density diversification - from 200 to 300 kg/m^3. The densities of the outer layers oscillated between 700-800 kg/m^3, whereas the inner layer densities ranged from 550-600 kg/m^3. In the obtained panels, the minimum density of the inner layers did not fall below 85% of the assumed value (600 kg/m^3).

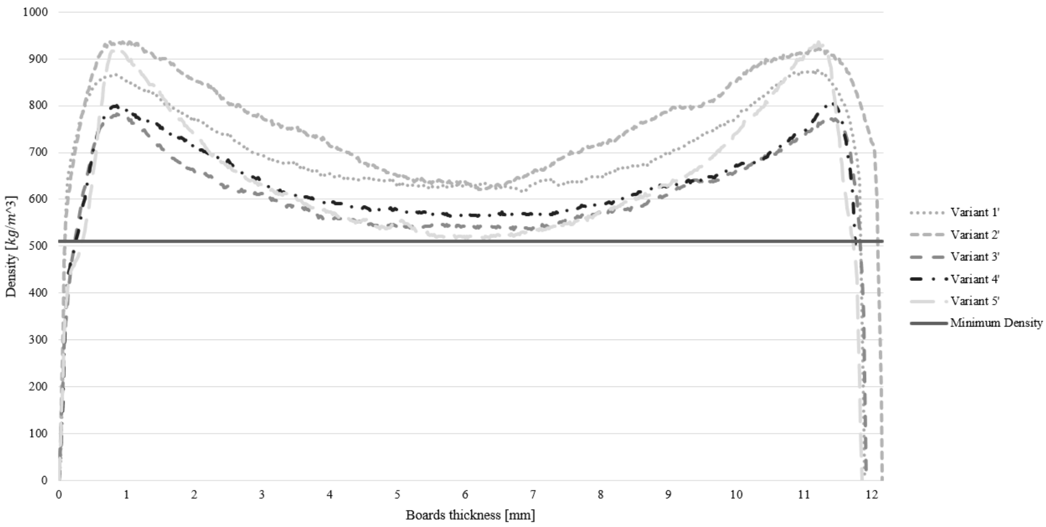

Figure 6. Density profile for each variant of pine boards

Panels with an average density of core layers lower than 85% are disqualified – standards requirements. The boards made of plantation wood were characterized by similar density profiles on the cross-section to boards made of common and typical raw material in Europe.

CONCLUSIONS

Based on the research carried out on single-layer particle-fibrous boards produced with a diversified share of wood particles obtained from European larch (*Larix decidua* Mill.) wood from plantations, it was found that:

1. The values of MOR and MOE for boards based on larch raw material with a fiber share of at least 50% or higher are comparable to boards made of particles obtained from pine wood, while in the other variants of boards, the obtained results indicate that with an increase in the share in the board of particles obtained from larch wood, the MOR and MOE values are decreasing.
2. Boards based on larch raw material with a particles share of 25% or higher, are characterized by lower swelling values after 2 and 24 hours of soaking in water than boards based on pine raw material.
3. The share of particles made of European larch wood in the board improves the IB value.
4. IB values for boards with the share of wood fibers at the level of 50% or higher, deviated from the requirements of the standard - this could have been influenced by the conditions of producing boards.
5. The density profile on the cross-section of boards made of plantation raw material is similar to boards made with the use of typical raw material - pine wood.

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Streszczenie. *Analiza wpływu udziału wiórów i włókien modrzewiowych na wybrane właściwości płyt wiórowo-włóknistych*. W pracy przedstawiono wyniki badań wpływu dodatku włókien i wiórów pozyskanych z drewna modrzewia europejskiego (*Larix decidua* Mill.) pochodzącego z upraw plantacyjnych, na wybrane właściwości płyt wiórowo-włóknistych, w porównaniu z płytami o tej samej budowie bazującymi na typowym surowcu przemysłowym (drewnie sosnowym) używanym przez europejski przemysł płyt drewnopochodnych. Różnice wykazano w badaniach tj.: wytrzymałość na zginanie statyczne (MOR), moduł sprężystości przy zginaniu statycznym (MOE), wytrzymałość na rozciąganie prostopadle do płaszczyzn (IB), spęcznienie na grubość po moczeniu w wodzie oraz profil gęstości. W badaniach MOR i MOE płyty modrzewiowe z minimum 50%-owym udziałem włókien charakteryzowały się porównywalnymi względem płyt sosnowych wartościami oznaczonych właściwości, natomiast w pozostałych wariantach lepszymi właściwościami charakteryzowały się płyty wytworzone z drewna sosnowego. Płyty modrzewiowe w większości wariantów odznaczały się zdecydowanie niższymi wartościami spęcznienia na grubość (wyjątek stanowiły płyty wykonane z włókien), niż płyty z drewna pochodzącego z upraw leśnych. Profil gęstości płyt na przekroju poprzecznym wykonanych z surowca plantacyjnego nie odznaczał się różnicami względem płyt wykonanych z surowca sosnowego.

Corresponding author:

Bartłomiej Pazio
Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW
159 Nowoursynowska St.
02-776 Warsaw, Poland
email: bartekpazio97@gmail.com
phone: +48 537 566 644