Леса России и хозяйство в них. 2025. № 2 (93). С. 104–113.
Forests of Russia and economy in them. 2025. № 2 (93). P. 104–113.

Научная статья
УДК 674.07
DOI: 10.51318/FRET.2025.93.2.012

ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ ПРОИЗВОДСТВА ДРЕВЕСНОВОЛОКНИСТЫХ ПЛИТ СРЕДНЕЙ ПЛОТНОСТИ (ДВП) С ИСПОЛЬЗОВАНИЕМ ДРЕВЕСИНЫ ВОСТОЧНОГО БУКА (*FAGUS ORIENTALIS* LIPSKY)

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Аннотация. ДВП (плита средней плотности волоконная) – это инженерный древесный материал, получаемый путем сочетания древесных волокон, смолы и других клеящих веществ, которые затем сжимаются под высоким давлением, чтобы сформировать плотную гладкую плиту. Он широко используется в производстве мебели, шкафов и интерьеров благодаря своей универсальности, гладкой поверхности и способности легко резаться и формоваться. Восточный бук – это прочная и эстетически привлекательная древесина, имеющая множество промышленных и коммерческих применений. Восточный бук занимает важное место во многих отраслях, особенно благодаря своей обрабатываемости, эстетическим качествам и долговечности. В этом исследовании были определены различные физические и механические свойства образцов плиты средней плотности (ДВП), произведенных из древесины восточного бука (*Fagus orientalis* Lipsky). Изученные свойства включают толщину, содержание влаги, плотность, увеличение толщины (24 ч), водопоглощение (24 ч), прочность на изгиб, модуль упругости, прочность на растяжение в перпендикулярном направлении, твердость поверхности и сопротивление выдергиванию шурупов. Результаты были сравнены с различными стандартными значениями и обсуждены.

Ключевые слова: среднеплотная древесноволокнистая плита, восточный бук, механические свойства, физические свойства

Благодарности: выражаем благодарность «Кастамону Энтеджри Аяк А. С.», его директору и менеджерам за поддержку.

Для цитирования: Исследование эффективности производства древесноволокнистых плит средней плотности (ДВП) с использованием древесины восточного бука (*Fagus orientalis* Lipsky) / Х. Пекер, О. Чамлибел, М. Э. Кара [и др.] // Леса России и хозяйство в них. 2025. № 2 (93). С. 104–113.

Original article

RESEARCH OF MEDIUM DENSITY FIBERBOARD (MDF) PRODUCTION PERFORMANCE USING ORIENTAL BEECH (*FAGUS ORIENTALIS* LIPSKY) WOOD

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Abstract. MDF (medium density fiberboard) is an engineered wood product created by combining wood fibers, resin, and other adhesives, which are then compressed under high pressure to form a dense, smooth board. It is widely used in the production of furniture, cabinets, and interior design due to its versatility, smooth surface, and ability to be easily cut and shaped. Oriental beech is a durable and aesthetically pleasing wood with numerous industrial and commercial applications. Oriental beech holds an important place in many industries, especially due to its workability, aesthetic qualities, and durability. In this study, various physical and mechanical properties of medium density fiberboard (MDF) samples produced from Oriental beech (*Fagus orientalis* Lipsky) wood were determined. The properties examined include thickness, moisture content, density, thickness swelling (24 h), water uptake (24 h), bending strength, elastic modulus, surface perpendicular tensile strength, surface hardness, and screw withdrawal resistance. The results were compared with various standard values and discussed.

Keywords: medium density fiberboard, oriental beech, mechanical properties, physical properties

Acknowledgements: we would like to express our gratitude to Kastamonu Entegre Agach A. Sh., as well as the Factory Director and Managers of Kastamonu, for their invaluable support.

For citation: Research of medium density fiberboard (MDF) production performance using oriental beech (*Fagus orientalis* Lipsky) wood / H. Peker, O. Chamlybel, M. E. Kara [et al.] // Forests of Russia and economy in them. 2025. № 2 (93). P. 104–113.

Introduction

Wood, due to its unique properties, has been used throughout history for construction, furniture, tools, and decorative items. Denser wood types are typically harder and stronger. The strength of wood varies depending on several factors, including the direction of the fibers. Wood is much stronger when cut along the grain than when cut across it (Mohammed et al., 2022; Majeed and Hussein, 2024).

The main properties of wood differ not only among various tree species but also within the same species. This results in difficulties in controlling wood properties during different processing stages. Furthermore, there are variations in the properties of various wood-based composite materials such as OSB, MDF, WPC boards, plywood, and GLULAM (Properties of un-torrefied…, 2023).

Composite materials are widely used in industries like aerospace and automotive due to their light weight and high strength. However, traditional production methods often lead to the use of substandard structures that result in poor physical and mechanical properties. Medium-density fiberboard (MDF) is a natural wood composite panel made by using wood fibers or additional lignocellulosic fibers combined with binders under heat and pressure (Gul et al., 2017;

Gul, 2021). Fiberboard, which is a homogeneous panel made from lignocellulosic fibers bound together with synthetic resins or other appropriate binding systems under heat and pressure, is produced using defibrator segments (Feasibility of incorporating…, 2012; Luo et al., 2022).

MDF is primarily used in industrial applications such as building materials, furniture, acoustic panels, and high-density fiberboard (HDF) laminated flooring due to its good mechanical and economic properties. It is known for its high strength, ease of processing, and durability in different weather conditions (Suchsland and Woodson, 1986; Mechanical and water…, 2009). The industry has defined specific marketing terms based on the density of MDF: HDF (density ≥800 kg/m^3), lightweight MDF (density ≤650 kg/m^3), and ultra-lightweight MDF (density ≤550 kg/m^3) (Halvarsson, 2010).

Urea-formaldehyde (UF) resins are typically used in the production of products where dimensional stability and surface smoothness are critical, such as particleboard and MDF. These resins can be formulated to cure anywhere from room temperature to 150 °C, and their curing times and temperatures can be adjusted accordingly. UF resins, often referred to as urea resins, are more economical than phenol-formaldehyde resins and are among the most commonly used adhesives for composite wood products. Due to their naturally light color, UF resins are particularly suitable for producing decorative products (Youngquist, 1999).

Previous studies have explored the production of MDF using different raw materials. Some examples of these studies include the following:

Roffael et al. (Medium density fibreboard…, 1992) reported that MDF boards made from 16-year-old poplar trees generally exhibited higher mechanical strength and lower thickness swelling compared to boards made from 5-year-old poplar of the same clone.

Yobp et al. (1993) conducted a study on the effects of steam pressure treatments at different levels of urea-formaldehyde resin on red maple wood chips.

Faraji (1998) used bagasse to produce MDF panels at various steam temperatures (170–180 °C) and times (5, 10 and 15 minutes). Zahedi (2000) examined MDF panels made from waste licorice roots, with varying steam and pressing times.

Chamlybel (2006) produced MDF panels using yellow pine, forest rose, and oak fibers in various proportions, concluding that forest rose could be used as a raw material for MDF production.

Yousefi (2009) investigated the suitability of canola straw for MDF production, evaluating variables such as steaming time, resin content, and pressing time. The results showed that MDFs made from canola straw were of acceptable quality compared to other non-wood plant materials.

Other studies have explored the use of walnut shells (Pirayesh et al., 2012), banana stalks and leaves (Physical and mechanical…, 2014), birch wood (Chamlybel, 2020), and ironwood (Chamlybel and Ajdyn, 2022) in MDF production. In particular, Moreno-Anguiano et al. (Use of Agave durangensis…, 2022) demonstrated the potential of using Agave durangensis Gentry in wood-based MDF panels up to 30 % in composition. Habibi (2007) experimented with producing MDF panels from reed, adjusting steaming temperatures and durations.

However, through a literature review, it was found that no MDF production has been conducted using Eastern Beech (*Fagus orientalis* Lipsky). This study, therefore, aims to explore the feasibility of producing medium-density fiberboard (MDF) from Eastern Beech wood and evaluate whether the resulting product meets the standard test criteria.

Materials and Methods

Raw Material: the beech wood (*Fagus orientalis* L.) used in this study was supplied from the Kastamonu Forestry Enterprise warehouses.

Adhesive: the urea formaldehyde resin used in this study was produced at the Kastamonu Integrated Adhesive Plant. The properties of the adhesive are as follows: pH: 7,0–8,6, viscosity (25 °C cps): 25–37 seconds, methylol groups: 12–15 %, urea-formaldehyde molar ratio (U:F): 1,04, density (20 °C): 1,227 g/cm^3, solid content: 64 ± 1 %, gel time (100 °C) (20 % $(NH_4)_2SO_4$): 40–70 seconds, shelf life: 70 days, and maximum free formaldehyde: 0,20 %.

Hardener: this material was obtained from a special company in the Gebze region. Ammonium sulfate ($(NH_4)_2SO_4$) was used as a catalyst during the production of urea formaldehyde resin under heat.

The properties of the 20 % ammonium sulfate solution are as follows: density: 0,99 g/cm^3 and pH: 6,6.

Paraffin: the dirty white liquid paraffin (with properties: solid content: 60 %, pH: 9–11, and density: 0,98 g/cm^3) was supplied by Mercan Kimya A. Ş. from Denizli Province.

The production parameters for the MDF panels used in this study are shown in Table 1.

In this study, 100 % beech wood chips were fed into the production process through the chip silo discharge screw. The chips were screened in the Dyne screen mechanical sieving system to sort them into standard sizes according to production requirements.

The pre-steaming process for the chips was carried out by applying steam at 145 °C and 2,8 bar pressure in the pre-cooking silo. After steaming, the chips were transferred to the Asplund defibrator system via a screw. In the Asplund defibrator, the cooking process was carried out at 188 °C and 8,0 bar steam pressure for 3,2 minutes. Prior to defibration, liquid paraffin was applied to the steamed chips with the help of the discharge screw.

The fiber production took place in the defibrator segments. Urea formaldehyde resin and hardener were added to the fibers via the blow line system. The fibers were dried in a dryer to a moisture content of 12 %. The dried fibers were homogenized in bunkers and mixed using rakes. At the spreading station, the fibers were formed into mats.

Cold pressing was applied to the mats under a pressure of 120–150 kg/cm^2. The continuous hot pressing process for the mats was carried out under the following parameters: press temperature 220 °C, press time 165 seconds, press speed 330 mm/s, and press pressure 32 kp/cm^2 to produce MDF boards. The conditioning process for the boards was performed in a star cooler. Then, the produced boards were sized in a sizing unit to dimensions of 18 × 2120 × 8430 mm (table 2).

Table 1

Production Parameters for MDF Panels

Raw Material	Beech (*Fagus orientalis* L) (%)	100
Urea Formaldehyde mole ratio 1,04 (65 % solid)	Resin solids based on dry fiber (%)	15,78
Liquid paraffin (60 %)	Paraffin solids based on dry fiber (%)	0,62
Hardening solution (20 %)	Hardeners solids based on dry fiber (%)	0,5
Constant pressing pressure	kg/cm^2	32
Constant pressing temperature	°C	220
Constant pressing time	seconds	165
Constant pressing speed	mm/sec	330
Plate measurements	mm	18 × 2120 × 8430

Table 2

Important Information Regarding MDF Production

Production Parameters		Consumption Used in 1 m^3 MDF Board Production
Press model	Siempelkamp ContiRoll hot press 2008 model, Krefeld, Germany)	–
Resin solids to dry fiber	15,78 %	99 kg/m^3
Urea formaldehyde solids ratio	64 ± 10 %	–
Paraffin solids ratio to dry fiber	0,62 %	4,34 kg/m^3
Hardener solids ratio to dry fiber	0,50 %	3,2 kg/m^3
Plate dimensions	18 × 2120 × 8430 mm	

The boards, which were produced over a period of 5 days, were conditioned in the stock area. Immediately after conditioning, both the upper and lower surfaces were sanded with different grit sandpapers (40, 80, 120 and 180 in sequence) to achieve boards with a thickness of 18 mm. The storage of the test boards was carried out using spacers on a smooth concrete surface without airflow. The produced MDF boards were conditioned according to the TS 642-ISO 554 (1997) standard to a moisture content of 12 % (at 20 ± 2 °C and 65 ± 5 % relative humidity).

The applied test standards were as follows: TS EN 326-1 (1999) for the selection, cutting, inspection, and reporting of test results for board samples; TS EN 324-1 (1999) for the determination of board thickness measurement; TS EN 322 (1999) for the determination of moisture content; TS EN 317 (1999) for the determination of swelling in water for particleboards and fiberboards; TS EN 323 (1999) for the determination of density of wood-based particleboards and fiberboards; TS EN 325 (2012) for the determination of the dimensions of test pieces for wood-based panels; TS EN 310 (1999) for the measurement of bending strength and modulus of elasticity of boards; TS EN 319 (1999) for the determination of perpendicular tensile strength of boards; TS EN 320 (2011) for the determination of screw withdrawal resistance from edges of boards; and ASTM D 1037-12 (2020) for the measurement of surface Janka hardness resistance of boards.

Results and Discussion

The determined moisture content, board thickness, thickness swelling (24 h), board density, and water absorption (24 h) results are presented in Table 3. According to these results, the physical properties of the boards were found to be: thickness of 17,79 mm, density value of 795,69 kg/m^3, moisture content of 4,99 %, thickness swelling (24 h) of 6,36 %, and water absorption (24 h) of 26,26 %. When comparing these results with the standard values, it is observed that the board thickness, density, and moisture content were determined to be above the desired values, thus meeting the standards (Table 3).

Table 3

Results of the determined moisture content, board thickness, thickness swelling, board density, and water absorption

Groups	Thickness	Moisture	Density	Swelling to Thickness (24 h)	Water Uptake (24 h)
Standard limit values for MDF	TS EN 324-1	TS EN 322	TS EN 323	TS EN 317	TS EN 317
Number of Samples	18 ± 0,2 mm	4–11 %	650–800 kg/m^3	< 12 %	Maximum 40 %
1	17,74	5,23	786,93	6,31	26,82
2	17,78	5,05	801,38	6,36	24,94
3	17,82	5,07	807,33	6,23	23,90
4	17,81	5,03	791,22	6,18	23,91
5	17,80	4,80	800,52	6,13	25,34
6	17,74	4,94	788,88	6,87	31,57
7	17,74	5,03	791,78	6,22	26,70
8	17,85	5,03	796,23	6,67	27,41
9	17,84	4,80	784,44	6,51	25,79
10	17,82	4,94	808,15	6,35	26,24
Averages	17,79	4,99	795,69	6,38	26,26
Standard Deviation	0,04	0,13	8,38	0,23	2,21
Minimum Result	17,74	4,80	784,44	6,13	23,90
Maximum Result	17,85	5,23	808,15	6,87	31,57
Coefficient of Variation	0,24	2,63	1,05	3,66	8,41

The determined bending strength, modulus of elasticity, screw withdrawal resistance, surface perpendicular tensile strength, and surface hardness results are shown in Table 4.

According to the results in Table 4, the surface perpendicular tensile strength was found to be 1,75 N/mm^2, the modulus of elasticity was 3907,41 N/mm^2, the bending strength was 42,53 N/mm^2, the surface hardness was 2,82 N/mm^2, and the screw withdrawal resistance was 1660,40 N. Since all the mechanical measurement results were above the desired values, it has been observed that the standards are met.

Yobp et al. (1993) reported that the resin content of MDF panels produced using red maple had a significant effect on all panel properties. An increase in resin content from 6 % to 12 % led to a 174 % increase in internal bond strength, a 68 % increase in modulus of rupture, and a 40 % increase in the modulus of elasticity. Additionally, thickness swelling and water absorption properties were reduced by 113 % and 60 %, respectively.

Faraji (1998) demonstrated that maximum bending properties and internal bond strength for MDF panels produced using bagasse were achieved at a vaporization temperature of 170 °C and a vaporization duration of 5 minutes. Moreover, it was noted that the swelling values of thickness in water decreased as the vaporization temperature and duration increased.

Yousefi (2009) reported that for MDF panels produced using canola straw, all the tested mechanical properties improved as the vaporization time increased. MDF dimensional stability was enhanced as the adhesive content increased, and IB values were positively affected as the pressing time increased.

Zahedi (2000) found that MDF panels produced from the waste of licorice roots, with a 20-minute vaporization time, 7-minute pressing time, and 10 % resin content, exhibited the highest strength properties.

Table 4

Results of the determined bending strength, modulus of elasticity, screw withdrawal resistance, surface perpendicular tensile strength, and surface hardness

Groups	Bending Strength	Elastic Modulus	Surface Perpendicular Tensile Strength	Surface Hardness	Screw Withdrawal Resistance
Standard limit values for MDF	TS EN 310	TS EN 310	TS EN 319	ASTM D 1037-12	TS EN 320
Number of Samples	> 20 N/mm^2	> 2200 N/mm^2	> 0.55 N/mm^2	> 1 N/mm^2	> 1000 N
1	41,44	3789,16	1,73	2,86	1672
2	42,01	3846,85	1,96	2,83	1734
3	43,21	3945,48	1,80	3,00	1843
4	41,52	3874,73	1,48	2,64	1577
5	40,34	3742,65	1,63	2,70	1502
6	40,90	3936,84	1,87	3,08	1681
7	43,28	3978,64	1,72	2,69	1531
8	44,66	3990,28	1,55	2,65	1760
9	43,28	3983,74	1,95	2,70	1537
10	44,66	3985,68	1,77	3,04	1767
Averages	42,53	3907,41	1,75	2,82	1660,40
Standard Deviation	1,51	89,49	0,16	0,17	117,67
Minimum Result	40,34	3742,65	1,48	2,64	1502,00
Maximum Result	44,66	3990,28	1,96	3,08	1843,00
Coefficient of Variation	3,56	2,29	9,24	6,00	7,09

In the study conducted by Chamlybel and Aydın (2022) using ironwood, the density value of the MDF panels was 0,694 g/cm^3, the swelling values for thickness after 2 and 24 h were 2,53 % and 6,01 %, respectively, and the moisture content was 5,01 %.

Pirayesh et al. (2012) found that for MDF panels produced using 100 % walnut shell particles, the bending strength was 5,86 N/mm^2, the modulus of elasticity was 1152,33 N/mm^2, the surface perpendicular tensile strength was 0,24 N/mm^2, the water absorption value was 32,84 %, and the swelling in water was 10,15 %.

Rashid et al. (Physical and mechanical…, 2014) compared two types of MDF panels produced from banana stems and leaves with commercially available boards. The densities were found to be 0,78 g/cm^3, 0,74 g/cm^3, and 0,72 g/cm^3, bending strengths were 50,91 N/mm^2, 45,30 N/mm^2, and 40,65 N/mm^2, and the modulus of elasticity values were 3939 N/mm^2, 3606 N/mm^2 and 3518 N/mm^2, respectively. Habibi (2007) reported that for MDF panels produced from reed, increased vaporization time and temperature led to a decrease in bending strength, modulus of elasticity, and surface perpendicular tensile strength. Furthermore, the dimensional stability results of the MDF showed that after 2 and 24 h of immersion in water, the thickness swelling decreased with higher vaporization time and temperature.

Conclusions

As a result of the study, it was found that the physical and mechanical properties of MDF boards produced from Eastern beech (*Fagus orientalis* L.) with a density of 795,69 kg/m^3 meet all the relevant standard criteria. According to the data in Table 2, the MDF board produced from beech wood has performed excellently. It is recommended to use 100 % beech wood in MDF production. These high-performance MDF products could be recommended as raw materials for the construction industry, the furniture sector, and other project-based products in special manufacturing.

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Статья поступила в редакцию 26.01.2025; принята к публикации 24.02.2025.
The article was submitted 26.01.2025; accepted for publication 24.02.2025.